ENERGY CONSERVATION
IN THE
PLASTICS PROCESSING INDUSTRY IN CANADA

Energy, Mines and Resources Canada | Energie, Mines et Ressources Canada

The Society of the Plastics Industry of Canada | La société des industries du plastique du Canada

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Energy, Mines and Resources Canada	Énergie, Mines et Ressources Canada

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ENERGY CONSERVATION
IN THE
PLASTICS PROCESSING INDUSTRY IN CANADA

PREPARED FOR
GOVERNMENT OF CANADA
DEPARTMENT OF ENERGY MINES AND RESOURCES
ENERGY CONSERVATION AND OIL SUBSTITUTION BRANCH
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FOREWORD

This study was undertaken with the encouragement and financial assistance of the Industrial Energy Division of the Energy Conservation and Oil Substitution Branch, Energy, Mines and Resources Canada. It has the cooperation and participation of numerous people in the plastics processing industry.

While the report has been reviewed for technical accuracy, the Society of the Plastics Industry of Canada and the Department of Energy, Mines and Resources are not liable in any way, either for statements made, conclusions reached or recommendations for the future.

Reference to trade names, specific commercial products, commodities, services or registered processes in this report does not necessarily constitute an endorsement, or recommendation by either the Society of the Plastics Industry of Canada, the Department of Energy, Mines and Resources or their associates or contractors.

ABSTRACT

A study of the current energy use in the Plastics Processing Industry and the potential for energy conservation. Included is a guide to assist processors in reaching these potential targets.

EXECUTIVE OUTLINE

The Plastics Processing Industry was surveyed to determine the status of energy conservation programs and the attitude toward conservation. The report outlines the types of energy used in the different plastic processes. New technology which will assist in energy savings was reviewed.

Estimates of potential savings were made including both procedural activities and plans which would involve higher capital investment. Part of the report is devoted to guidance to the processors in establishing and operating successful energy conservation programs.

SUMMARY

The Canadian Plastics Processing Industry is comprised of approximately 1,800 firms who mold, extrude, shape or fabricate plastic resin into finished products or component parts. It employs approximately sixty thousand persons and shipped an estimated 4.7 billion dollars in 1981.

From some outstanding examples, the industry was perceived to have good potential for energy conservation. However, only a low percentage of firms were reporting to the Industry Task Force. Firms are mostly small in size. Over 50% have less than 20 employees and over 90% have less than 100 employees.

It was felt a study of this situation would disclose the reasons for the reluctance of the processors to involve themselves in energy conservation and would present the opportunity to estimate the potential energy savings for the future.

The survey showed two main causes for this reluctance. Most small or medium size firms perceive that a program would take too much time and would require too great a capital investment. Those firms which have tried a program seriously, have found this not to be the case and in fact, have been surprised at how much money they could save with little effort. The estimates show that about 3/4 of the potential savings of 25%, on an annual basis for 1984, comes from procedural methods, or by capital expenditure with less than two years pay-back.

The other aspect that arises is the relatively low percentage cost of energy compared to other manufacturing costs involved in plastic processing. This percentage varies depending on the process, but typically injection molding shows energy as approximately 6% of manufacturing cost excluding raw material. If raw material is included, then energy cost become less than 3% of total manufactured cost of product.

Many machinery manufacturers were interviewed and a great deal is being engineered in new energy efficient designs. This will ultimately help the processor to reduce energy consumption as equipment is replaced or additional machines puchased.

The use of modern technology such as microprocessor controls, will not only save energy, but will improve productivity. These are readily available for most plastic processing equipment.

The final estimate of energy conservation, in the Plastics Processing Industry in Canada, is 25.2% on an annual basis for the year 1984. This amounts to nearly 4 million Gigajoules (10^9) or the equivalent energy to heat 31 thousand homes for a full year.

This report also devotes considerable time in developing a guide to processors, to assist them in developing energy saving programs. This is a simple, inexpensive approach recognizing the size of the majority of processors in the Canadian industry.

A number of technical article reprints are included for easy reference. These deal with the new energy efficient machines and they also outline, in detail, methods of conservation processors can use in their operations.

AVANT-PROPOS

La division de l'Energie industrielle de la direction de l'Economie d'énergie et du remplacement du pétrole du ministère de l'Energie, des Mines et des Ressources du Canada a encouragé et appuyé financièrement la réalisation de la présente étude. La division a pu aussi compter sur la collaboration et la participation d'un grand nombre d'intervenants dans l'industrie du plastique.

La rapport, tel que soumis, a fait l'objet d'un examen attentif et bien que l'information d'ordre technique ait été vérifiée, ni la société des industries du plastique du Canada, ni Energie, Mines et Ressources Canada peuvent être tenus responsables des affirmations qui sont faites, des conclusions qui sont tirées ou des recommandations pour l'avenir qui sont formulées dans ce rapport.

La mention, dans ce rapport, de marques de commerce, de produits commerciaux spécifiques, de biens et de services ou de procédés enrégistrés ne constitue pas nécessairement une approbation ou une recommandation de la part de la société des industries du plastiques du Canada, d'Energie, Mines et Resscurces Canada, de leurs associés ou de leurs entrepreneurs.

SOMMAIRE

Il s'agit d'une étude sur la consommation actuelle d'énergie dans l'industrie des matières plastiques et sur le potentiel d'économies d'énergie. Le rapport comprend un guide destiné à aider l'industrie à atteindre cet objectif.

GRANDES LIGNES À L'INTENTION DE LA HAUTE DIRECTION

On a fait une enquête auprès de l'industrie des matières plastiques pour déterminer l'état de programmes d'économies d'énergie appliqués par l'industrie et son attitude envers le concept d'économie d'énergie. Le rapport expose les types d'énergie consommés dans les divers procédés de fabrication de matières plastiques. Il passe en revue la nouvelle technologie capable d'aider à réaliser des économies d'énergie.

On a évalué les économies d'énergie réalisables, tant pour les activités simples de modification de procédés que pour les plans qui supposeraient un apport de fonds plus important. Une partie du rapport est consacrée à l'orientation de l'industrie dans l'établissement et l'exécution de programmes efficaces d'économie d'énergie.

RÉSUMÉ

L'Industrie canadienne des matières plastiques se compose d'environ 1 800 sociétés qui moulent, forment ou fabriquent de la résine plastique pour en faire des produits finis ou des pièces composantes. Elle emploie environ 60 000 personnes et a livré des produits d'une valeur estimative de 4,7 milliards de dollars en 1981.

À partir de quelques exemples frappants, l'industrie a été percue comme offrant de bonnes possibilités d'économie d'énergie. Toutefois, seul un faible pourcentage de sociétés a approché le groupe de travail sur l'industrie. La plupart des sociétés sont de petites entreprises; en effet, plus de 50% comptent moins de 20 employés et plus de 90%, moins de 100.

On a pensé qu'une étude de cette situiation dévoilerait les raisons qui expliquent la réticence de l'industrie à s'engager dans des programmes d'économie d'énergie et permettrait d'évaluer les potentiels d'économie d'énergie pour l'avenir.

L'enquête a révélé qu'il existe deux principales causes à cette réticence. La plupart des petites ou moyennes entreprises considèrent que la participation à un tel programme exigerait beaucoup trop de temps et nécessiterait trop d'investissement. Les sociétés qui se sont engagées sérieusement se sont rendu compte qu'il n'en était rien et se sont plutôt étonnées de l'importance de l'épargne qu'elles pouvaient réaliser sans trop d'effort. Les prévisions révèlent qu'environ trois quarts des économies annuelles réalisables (25% pour 1984) découlent de simples modifications des méthodes ou de dépenses en capital qui se récupéreraient en moins de 2 ans.

L'autre aspect à considérer est le coût relativement faible de l'énergie nécessaire pour le traitement des matiéres plastiques comparativement à d'autres coûts de fabrication. Ce pourcentage varie selon le procédé, mais généralement, le coût de l'énergie nécessaire au moulage par injection

représente environ 6% du coût de fabrication, sans compter la matière première. Si on l'inclut dans le calcul, le coût de l'énergie devient alors inférieur à 3% du coût de fabrications total du produit.

Beaucoup des fabricants de machines interrogés ont déclaré qu'ils étudiaient actuellement de nouvelles conceptions à meilleur rendement énergétique, ce qui permettra éventuellement à l'industrie de réduire sa consommation énergétique au fur et à mesure qu'elle remplace du matériel existant ou achète de nouvelles machines.

Non seulement le recours à la technologie moderne comme les commandes par microprocesseurs permettra-t-elle d'économiser de l'énergie, mais elle améliorera la productivité. Il est facile de se procurer ces contrôles pour la plupart des machines utiliseés pour le traitement des matières plastiques.

La plus récente prévision d'économie d'énergie dans l'industrie des matières plastiques au Canada est de 25,2% pour l'année 1984, ce qui équivaut à près de 4 millions de gigajoules (10^9) ou à l'énergie nécessaire pour chauffer 31 000 résidence pendant toute une année.

Une bonne partie du rapport est censée servir de guide à l'industrie pour l'aider à élaborer des programmes d'économie d'énergie. Il s'agit-là d'une démarche simple et peu coûteuse qui tient compte de l'importance de la majorité des entreprises de cette industrie canadienne.

Le rapport comprend un certain nombre d'articles techniques réimprimés pour faciliter la consultation. Ils portent sur les nouvelles machines à grande efficacité énergétique et décrivent également en détail les méthodes que peuvent utiliser les exploitants pour ménager l'énergie dans leurs opérations.

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ENERGY CONSERVATION IN THE PLASTICS PROCESSING INDUSTRY IN CANADA

1. INTRODUCTION

This study was instigated with two major objectives in mind. The first was to assess the energy saving potential within the industry. The second was to develop information which could be used by the industry to reach those energy saving targets.

Both of these objectives required a detailed survey of a representative number of firms in the different segments of the processing industry to determine what types of procedures and techniques were already being used. It was particulary important to determine the varied energy requirements in the different processes and identify which processes were more adaptive to energy conservation. It was also necessary to find out what new technology was being developed by the machinery manufacturers that would assist the industry in these areas.

It was felt valuable information could be available in Europe where high energy costs have given conservation a high priority. Thus contacts were made with a number of processors and machinery manufacturers as well as plastic connected trade associations in Germany and Belgium.

There was unanimous cooperation and assistance from every firm contacted in connection with the study. Naturally the economic advantages were foremost in everyone's mind and there was considerable discussion about the current problems of manpower restrictions and restraints on capital investment. Thanks and appreciation go to all those individuals who spent considerable amounts of valuable time explaining their operations, plans and ideas.

1.1. ENERGY EFFICIENCY IN PLASTIC PRODUCTS

Outside of the terms of reference of this particular study, but of vast interest to the industry, government and consumers, is the fact that products and components made of plastic are more energy efficient than if those same products had been made from other materials.

There have been some very extensive studies made on this subject. For anyone wishing to look further into these details, please refer to the following excellent articles.

TOTAL ENERGY IMPACT OF THE USE OF PLASTIC PRODUCTS IN THE U.S.A.
Published January 1981, by
THE SOCIETY OF THE PLASTICS INDUSTRY INC.
355 Lexington Avenue, New York, N.Y. 10017
Prepared by Franklin Associates Ltd.

THE ENERGY CONTENT OF PLASTIC ARTICLES
HOW PLASTICS HELP SAVE ENERGY
Published April 1982, by
ASSOCIATION OF PLASTICS MANUFACTURERS OF EUROPE (APME)
Avenue Louise 250 Box 73
1050 Brussels, Belgium

2. INDUSTRY PROFILE

2.1. DESCRIPTION OF THE INDUSTRY

It would be wise at this early stage to clarify what is meant by the plastics processing industry for the purpose of this study. We are really referring to any firm who processes plastic resin, transforming it into any form, shape or sheet, whether it be a finished product or component part. We are NOT referring to the petrochemical industry who manufacture the basic resin.

In 1974 a detailed survey was made of the industry by Government of Canada, Department of Industry Trade and Commerce with the assistance of the industry and some of the Provincial trade departments. At that time the survey recognized 1400 plastic processing establishments.[1] The industry now feels the current figure is 1800. Refer also to Statistics Canada figures below. Statistics Canada group plastic processors under SIC 165, but under our definition there are many processors who get classified by Statistics Canada under other major industrial classifications. Examples would be automotive, appliance, toy and many others. The extensive survey in 1974 concluded that Statistics Canada classification SIC 165 only captures approximately 53% of the processing which we include in our definition of the industry.[1] Statistics Canada in 1980 report 873 establishements so if we apply our 53% factor, we arrive at 1647 processing firms in 1980.[2]

It is interesting, and reassuring, to note that in Europe where the processing industry has accurate statistics on this very subject, the split is within 6%. They report 48% as custom processors and 52% as captive. Their classification of "captive" woud appear to be the same as that which Statistics Canada captures in industries other than Plastics Fabrication.[3]

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[1] A Report on The Plastics Processing Industry in Canada Department of Industry, Trade and Commerce 1977 (2.1. page 2)

[2] Plastics Fabrication Industry Catalogue #47-208 (page 1) Statistics Canada 1980.

[3] Gesamtverband Kunststoffverarbeitend Industrie E.V. (GKV) The Association of the Plastics Processing Industry.

2.2. MAJOR PROCESSES

The complexity of the industry is magnified because of the many different process technologies. The major processes are listed below. The percentage figures in each process come from the 1974 survey and may have shifted in the intervening time.[4]

MAJOR PROCESSES	% OF ESTABLISHMENTS
Reinforced Plastics	23
Extrusion (including film)	22
Injection and Compression	19
Fabrication (from film, sheet, rod)	11
Thermoforming	8
Foam Molding (including expanded bead)	6
Blow Molding	5
Rotational Molding	1
Calendering	1
Other	4
	100%

In the "other" group would be such processes as Structural Foam, Reaction Injection Molding and other processes which have gained greater prominence in the intervening time.

2.3. REGIONAL DISTRIBUTION

Plastic Processors are heavily concentrated in Ontario and Quebec, as shown in the following Statistics Canada figures for 1980.[5] Keep in mind these figures cover SIC 165 only, but there is no reason to believe the percentages would change to any extent for the total number of processors. If anything they might lean even more heavily toward Ontario and Quebec.

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[4] A report on the Plastics Processing Industry in Canada. Department of Industry, Trade and Commerce 1977 (2.2 page 3)

[5] Plastics Fabricating Industry Catalogue #47-208 (page 1) Statistics Canada 1980.

PROVINCE or TERRITORY	NUMBER	PERCENTAGE
Newfoundland	0	-
Prince Edward Island	1	00.1
Nova Scotia	11	01.3
New Brunswick	7	00.8
Quebec	222	25.4
Ontario	452	51.8
Manitoba	32	03.7
Saskatchewan	15	01.7
Alberta	58	06.6
British Columbia	75	08.6
Yukon and North West Territories	0	-
	873	100.0

The fact a large percentage of Canadian processors, as compared with U.S. competitors, are located in areas of longer and colder winters, is bound to be reflected in the energy costs for plant heating. However, in terms of opportunity for conservation it presents real potential.

2.4 ESTABLISHMENT SIZE

The plastics processing industry is basically made up of small and medium size firms. In the past, the relatively low capital investment and threfore the ease of entering the industry, has meant a constant growth in the number of small entrepeneurs starting a new firm. This may gradually change as high technology and therefore higher capital investment costs, make it more difficult for someone to enter the industry on a sound basis.

There are fewer than 20 employees in 54% of the firms covered by SIC 165. Further, there are fewer than 100 employees in 91.5% of those same firms.

When figures are projected for the concept of the industry used in this study, it may not change the above percentages greatly. Captive operations included in other industry statistics range all the way from one machine involving less than 10 employees (directly related to plastics), to operations that are the largest processors in Canada.

A chart showing total employment including both hourly and salaried employees is shown below. This is for SIC 165 for 1980.[6]

GROUP	ESTABLISHMENTS	ALL EMPLOYEES	PERCENTAGE
0 - 4	174	346	20.0
5 - 9	132	891	15.1
10 - 19	167	2 365	19.1
20 - 49	212	6 587	24.3
50 - 99	113	7 780	13.0
100 - 199	51	7 121	5.8
200 - 499	24	7 541	2.7
	-	-	-
	873	32 631	100.0

If we apply the same formula, saying SIC only captures 53% of the total processing industry, the employment figures in 1980 would have been 61,568 plastic processing employees including both hourly and salaried.

This figure can be challenged and is certainly controversial. It is based on the assumption that the 53% basis of projecting the total industry from the

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[6] Plastics Fabricating Industry Catalogue #47-208 (page 2) Statistics Canada 1980.

SIC 165 statistics, is valid for number of employees as well as number of establishemts. At various times and places this figure has been estimated anywhere from 49,000 to 62,000 for that year. The fact remains that the employee figures for the captive operations, covering their plastic processing employees only, cannot be verified in any current statistics. We cannot perceive any reason for the same 53% formula not being applied.

The small size of so many processors becomes a significant factor when it comes to an activity such as energy conservation. The small firms do not have the manpower or the resources, to tackle situations which do not appear to be critical or urgent. Therefore they are rated a low priority amoung the many problems facing a processor on a day to day basis.

2.5 INDUSTRY SHIPMENTS

In 1980 shipments of all processors reporting under SIC 165 was 2.181 billion dollars.[7] Therefore we would estimate the total sales of the industry (according to our definition) for that year to be approximately 4.116 billion dollars.

In 1981 the total industry figure was approximately 4.7 billion dollars in current dollars and no adjustment for inflation.

3. THE SURVEY

3.1 SCOPE AND GENERAL DESCRIPTION

The reasoning behind making personal calls on processors, was to determine first hand their attitude toward energy conservation. It was hoped to find out what types of normal and innovative actions the processors were taking.

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[7] Plastics Fabricating Industry Catalogue #47-208 (page 8) Statistics Canada 1980.

Obviously with money and time restraints, it was impossible to contact all 1800 processors. Seventy processors were chosen who represented all of the various processes. These were chosen to give variety in geographical location as well as size. A list of the processors is attached in Appendix A.

A questionnaire was developed to produce potentially useful data to later assess the status of the industry and provide assistance and guidance for the industry in the future.

It was the intent to contact a number of machinery manufacturers to determine what new technology was being developed which would be of assistance to the industry in the future.

It quickly became apparent that the plastic processing machinery manufacturers had been working hard on research and development to produce energy efficient machines.

The also had a great deal of information in connection with actual processing procedures which could be of assistance to the processors.

Therefore this area of the survey was expanded to attempt to contact more major plastic machinery manufacturers. Where personal calls were not possible, some very productive contacts were made by telephone and mail. In all, 35 machinery and auxiliary equipment manufacturers and representatives were contacted. These included Canadian manufacturers, some in the United States, two in Germany, and Canadian representatives of Japanese equipment. A list of these firms is attached. (appendix B)

A number of the plastic resin producers were able to supply assistance through their technical or R and D departments. A list of those firms who contributed information is attached. (appendix C)

The trade associations were extremely helpful. The Society of the Plastics Industry of Canada and the Society of Plastic Engineers gave assistance. In Germany three associations assisted. The resin producers association, the machinery manufacturers and the processors association all were most generous with their assistance. The plastic processor institute in Germany contributed valuable information. All of these associations are listed under their full and correct names, along with the individuals who assisted, in Appendix D.

Finally an extensive literature search was made through many trade magazines, company publications and catalogues to uncover as much data as possible so reference could be made to articles already published.

3.2 SURVEY STATISTICS

The first group of questions were aimed at determining the organizational approach to energy conservation.

(A) Do you operate a?	%
Formal program -	34.3
Informal program -	45.7
No Program -	20.0

(B) Was your program started?	%
Prior to 1979 -	24.3
1979 or since -	55.7
Not started yet -	20.0

(C) Is your program administered by?	
Energy officer -	15.7
Committee -	20.0
General management -	44.3
Nobody particular -	20.0

(D) Do you tabulate energy usage?

Weekly -	8.6
Monthly -	40.0
Yearly -	10.0
Just check bills -	41.4

(E) Do you use a standard unit of production for comparing energy use?

Yes -	44.3
No -	55.7

The next two questions identified actual energy types used in the industry.

(F) What energy type do you use for processing?

Electricity -	100.0
Natural gas -	12.8*
Oil -	
Steam -	7.1*

*Gas and Steam used in process as well as electricity.

(G) What energy type do you use for building heat?

Electricity -	5.7
Natural gas -	91.5
Oil -	1.4
Steam -	1.4

The next group of questions try to identify the results of a company's energy conservation program.

(H) Can you identify areas of energy conservation?

	%
Yes -	60.0
NO -	40.0

(I) Can you translate any areas of energy saving into dollars?

Yes -	25.7
No -	74.3

(J) Have you set energy conservation targets for your firm?

Yes -	18.6
No -	81.4

(K) Do you report annually to the Industry Energy Conservation Task Force through SPI?

Yes -	20.0
No -	80.0

Following are some questions to explore the effect of any exterior influences.

(L) If the Government was to assist on energy conservation programs, which method would be most effective?

Grants -	77.1
Tax concessions -	22.9

(M) Have you used any outside assistance in your energy saving program?

Energy Bus audit -	20.0
Energy consulting firms -	10.0
None -	70.0

(N) Have you received any financial assistance on your program?

	%
Porvincial Grant -	8.6
Federal Grant -	-
None -	91.4

The balance of the questions involved general information on actual energy saving techniques already in operation or planned for the future. These will be included in the section of this report where we deal with suggestions and proposals to assist processors in their programs.

3.3 COMMENTARY ON SURVEY STATISTICS

3.3.1 ENERGY PROGRAM OPERATION

The survey shows quite clearly that a large percentage of firms have no energy conservation program or one that is operated with an informal approach. This latter group covers a wide range of operations. Some informal programs are quite effective because of the individuals involved.

Others are really no program at all. Part of this became obvious in the personal interviews and cannot be reflected accurately in the statistics. However, a clue to this situation is contained in the 55% active only since 1979, the 44% left to general management and the 41% who do not track their consumption but only check the billings.

General attitudes toward energy conservation became a prime target in the interviews and cannot be captured in questionnaire statistics. There were some comments on the lack of urgency of conservation which are undoubtedly brought on by the current situation on world markets. However, nost firms view energy conservation in economic terms and give it priority rating in their operations accordingly.

A high percentage of plastic processing firms are giving energy conservation a low priority rating because it is a low percentage relative to some other components of their factory cost. This is particularily true under today's economic conditions. Many people discussed restraints due to staff levels and a freeze on capital expenditure.

To bring this question into focus, let's check those percentages. Because of the variation in energy requirements in the different processes, any average figures can be dangerous. However, narrowed down to one segment such as injection molding, we see that energy costs are between 5 and 6% of manufacturing costs (direct and indirect but excluding raw material). If your costing methods consider full factory cost of manufactured product including raw material, then the percentage drops to 2 to 3%. There is a fairly wide range even within one process segment due to product mix and raw material processing requirements and cost.

With these percentages in mind, we should recognize good management procedures in the use of time and resources available. However, rather than being locked into percentages, should we not look at absolute dollars and realize any money saved in this manner is worthwhile especially under today's market conditions, where it is difficult to make a profit. This can only work if energy saving can be achieved within a time and cost framework that does not detract from those other areas of manufacturing cost.

Many firms are finding this approach very feasible and are willing to share their methods with the rest of the industry. Later in the report these will be discussed in detail.

3.3.2 ENERGY SOURCES

All firms in the plastics processing industry use electricity as the prime source of energy for their manufacturing process. Of course the expanded bead process needs steam as a basic requirement as well. Likewise some processes need natural gas in either a drying or surface treatment operation.

Building heat is now predominantly produced by natural gas. In some areas the industry is virtually "off oil". Both our survey and the Society of the Plastics Industry Task Force reporting figures, would indicate an extremely small percentage still using oil. This is a little misleading as in some areas such as Quebec, there is not universal natural gas distribution and the percentage is higher.

3.3.3 IDENTIFICATION AND REPORTING

The survey would indicate that a lot of people are actively pursuing energy conservation in various ways, but it is equally obvious they are not tracking the results. 60% can give examples of actions taken to render savings but only 25% can equate this to dollars saved.

Likewise only 18% have set targets for themselves and only 20% are reporting to the Industry Energy Conservation Task Force through the SPI. It is safe to say that these percentages are higher than statistics for the entire industry since the average size of the firms surveyed was larger than the average of the industry. Also in some cases firms were chosen for the survey because it was known they were active in the energy saving area and would therefore have valuable information to supply.

3.3.4 EXTERIOR ASSISTANCE

Three quarters of those firms surveyed felt capital assistance grants would be the most effective approach to activating firms in energy conservation programs where long payback of investment was involved. The current high cost of money and the depressed economic conditions may have had some influence on these answers at this particular time.

Some suggestions were made other that straight tax considerations and fast write-offs. Some firms felt any Government assistance should be more tightly tied to "proven" energy saving programs and handled through forgiveable loans.

Several firms felt Government money could be better spent by educational and technical assistance which could be made available to the processors on a consulting basis. This seems to be in response to the complaints of manpower, technical research and capital shortage in the industry.

In some ways this contradicts the fact that only 20% of firms had taken advantage of the Energy Bus Program and only 10% had used consulting firms.

Also, only 8% had actually received grant assistance through Provincial or Federal plans. A number of those who had applied for grants complained of experiencing excessive delays and bureaucratic red tape.

4. INDUSTRY ENERGY CONSUMPTION

4.1 CONSUMPTION STATISTICS

Statistics Canada collects the energy consumption data for the industry under CONSUMPTION OF PURCHASED FUEL AND ELECTRICITY.[8]

As in other statistics, this only captures those processsing firms under catagory SIC 165. Unfortunately, 1981 figures have not been tabulated at the time this report is being completed, so the following are figures for 1980.

1980 CONSUMPTION OF PURCHASED FUEL & ELECTRICITY
PLASTICS PROCESSING INDUSTRY (SIC 165)[9]

ENERGY TYPE	CONSUMPTION ('000's)	GIGAJOULES (10^9)	%
NATURAL GAS	92,251M^3(cubic meters)	3,435,660	41.21
GASOLINE	8,061 Litres	279,394	
KEROSENE	435 Litres	16,391	
DIESEL OIL	3,895 Litres	150,659	19.27
LIGHT FUEL OIL	7,014 Litres	271,302	
HEAVY FUEL OIL	21,294 Litres	888,598	
LIQUIEFIED PETROLEUM GAS	2,195 Litres	56,038	00.67
ELECTRICITY	899,615 kWh (kilowatt hours)	3,238,614	38.85
	TOTAL	8,336,656	100.00

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[8] Statistics Canada - Consumption of Purchased Fuel and Electricity Catalogue #57-208

[9] Statistics Canada - 1980 - Consumption of Purchased Fuel and Electricity Catalogue #57-208 Tabulated but unpublished at time this report completed.

If the Statistics Canada figures are projected to include all firms in the Plastics Processing Industry as defined in this report, the total energy consumption for 1980 would be as follows:

1980 CONSUMPTION OF PURCHASED FUEL & ELECTRICITY
ESTIMATED TOTAL PLASTICS PROCESSING INDUSTRY

ENERGY TYPE	CONSUMPTION ('000's)	GIGAJOULES (10^9)	%
NATURAL GAS	174,058M^3 (cubic meters)	6,482,357	41.21
GASOLINE	15,209 Litres	527,144	
KEROSENE	821 Litres	30,935	
DIESEL OIL	7,349 Litres	284,359	19.27
LIGHT FUEL OIL	13,124 Litres	511,981	
HEAVY FUEL OIL	40,177 Litres	1,676,586	
LIQUIEFIED PETROLEUM GAS	4,141 Litres	105,720	00.67
ELECTRICITY	1,697,387 kWh (kilowatt hours)	6,110,593	38.85
	TOTAL	15,729,585	100.00

NOTE -

CONVERSION FACTORS	GIGAJOULES (10^9)
Natural Gas - 1M^3 (cubic metre)	.03723
Gasolene - 1 Litre	.03466
Kerosene - 1 Litre	.03768
Diesel Oil - 1 Litre	.03868
Light Fuel Oil - 1 Litre	.03868
Heavy Fuel Oil - 1 Litre	.04173
Liquefied Petroleum Gas - 1 Litre	.02553
Electricity - 1kWh (kilowatt hour)	.00360

Although the figures in the first list (SIC 165) for 1980 are the latest available from Statistics Canada, we do have 1981 reports from the Plastics Porcessing Industry Energy Conservation Task Force.

These comprise only the consumption from those firms reporting to the Task Force.[10]

1981 ENERGY CONSUMPTION PLASTICS PROCESSING INDUSTRY

INCLUDES ONLY THOSE FIRMS REPORTING TO TASK FORCE

ENERGY TYPE	CONSUMPTION GIGAJOULES (10^9)	%
NATURAL GAS	833,200.7	56.1
FUEL OILS (all types)	18,217.8	1.2
LIQUIEFIED PETROLEUM GAS	5,840.2	0.4
ELECTRICITY	626,963.2	43.3
TOTAL	1,484,221.9	100.00

Some comments in connection with the foregoing figures would be appropriate at this time. The energy consumption of the firms reporting to the Plastics Processing Industry Task Force, would appear to be in the range of 10 to 13%. With this relatively small sampling and also the sampling of this survey (70) firms, it produces some conflicting information in connection with the percentage of fuel oils still being used.

Both the Task Force figures and our survey, indicated the industry was virtually "off oil". However, the Statistics Canada figures for 1980 (latest available) indicate nearly 20% of the energy used by the industry is still fuel oils of different types.

On investigating this matter further and following up on some of our original interviews, we found that in Quebec there are large areas without natural gas distribution and firms are either forced to continue with oil for plant heating or change to electricity. This may be the case in other localized areas in Canada. Therefore, we must assume our survey results in this matter are typical.

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[10] 1981 Report - Canadian Industry Program For Energy Conservation. Page 58

We should also point out, however, that the number of oil to gas conversions was accelerating in 1981 and 1982, so hopefully statistics Canada figures, when they are available for those years, will show a futher decline in the use of oil.

Every effort was made to cross check consumption figures but all projections were made on the estimates previously discussed, where it is necessary to project a very large percentage of the industry beyond the actual reported Statistics Canada figures.

4.2 POTENTIAL ENERGY SAVING (GENERAL COMMENTS)

A major objective of this survey was to determine the potential of energy conservation in the complete Plastics Processing Industry. It became apparent early in the study that different processes have considerable different potential for conservation. This is due to the fact that some processes are more energy efficient in the types of equipment used. Some have greater scope for waste energy in procedural activities.

If any useful estimates were to be made, it became essential to segregate the different processes with regard to the energy consumption in each process. Once again the lack of adequate statistics was a major stumbling block.

Statistics Canada collects data on number of establishments, sales, volume, number of employees etc., but this was not going to help in this protion of the project.

What was needed was equipment capacity and energy consumption for that particular equipment in order to make meaningful projections.

In Germany the industry has statistics, for instance, on the total clamp capacity of all injection molding machines in operation. For future use in Canada it would be very helpful in certain analysis, to have an accurate figure on the total capacity of the industry. Rating the capacity of injection molding in clamp capacity, and of extrusion in kilograms per hour, would give a much more accurate base than sales figures which can vary widely because of product mix and resin costs.

Another approach would be to know the toal resin processed by each segment of the industry and relate that to an energy cost per unit of production. However, at this stage there are no developed averages for production energy costs for the different processes. We saw by the survey statistcs that not many firms are using any program to develop their unit energy cost. Once again, looking at Germany where energy costs have been high for many years, we find it is standard practice to calculate energy cost per unit of production or per kilogram processed. This is also the case in Japan.

As a substitute for these more accurate methods, we tried to estimate the actual number of machines in each process. Of course, this information is not available at any one source. We elected to ask the processors we interviewed, how many machines were in their segment of the industry in Canada. We felt narrowing it down to their actual competitors would produce some accurate figures in most segments. Where there was a range of estimates we used the average.

This list is presented in order to show the estimated potential savings in energy in each process segment.

Knowing the figures will be controversial, we are also showing our rating as to percentage of accuracy as to the number of machines in each process.

The estimated potential savings in each segment comes from survey statistics. these range widely even within the same process. It probably depends on how serious a firm is with their energy conservation program and also how energy conscious they have been in controlling their costs. Therefore we have made a judgement decision with the knowledge that became available to us, in arriving at the percentages shown.

One thing stood out strongly in the interviews. Every single firm who had made a serious effort to operate an energy conservation program had been amazed at what they had accomplished. In most cases it had been accomplished with very little capital expenditure and relatively little time. Conversely, those who have not started a serious program seem to shy away from it because they perceive it costing a lot of money or taking up too much valuable time.

4.3 ESTIMATES ON POTENTIAL SAVINGS IN ELECTRIC ENERGY

The following estimates cover savings which can be made with no capital expenditure, (through procedureal methods) or with capital investments with less than 2 years payback. The total savings are on an annualized basis and should be achieved by the second year of operation.

4.4. LONG RANGE POTENTIAL SAVINGS IN ELECTRIC ENERGY

The technology is already available to processors to go beyond the procedural conservation techniques. Machinery manufacturers have been very active in improving their equipment as to energy efficiency. Process control developments are far past the experimental stage. If a processor is purchasing new equipment this can all be taken into consideration. Further details in connection with energy efficient equipment will be discussed in greater detail later in this report.

The point here is that electric energy comprises a large percentage of the energy used in plastic processing.

POTENTIAL ELECTRIC ENERGY SAVINGS
USING PROCEDURAL METHODS WITH NO CAPITAL EXPENDITURE
OR CAPITAL EXPENDITURE WITH LESS THAN 2 YEARS PAYBACK

PROCESS	NUMBER OF MAJOR MACHINES	ESTIMATED ENERGY CONSUMPTION 1982 (GIGAJOULES) (10^9)	ESTIMATED % POTENTIAL SAVINGS	ESTIMATED ANNUAL SAVINGS (GIGAJOULES) (10^9)
BLOW MOLDING				
INDUSTRIAL	75*	64,120	15	9,618
BOTTLE	250*	239,400	15	35,910
CALENDERING	9*	55,400	20	11,080
COMPRESSION INCLUDING TRANSFER SMC	330*	316,100	20	63,220
EXPANDED BEAD				
SHEET	35*	43,780	10	4,378
CUPS	250**	111,150	10	11,115
MOLDED SHAPES	100*	44,460	12	5,335
EXTRUSION				
FILM	350*	383,,040	12	45,965
PIPE DRAIN	40*	24,630	10	2,463
PIPE PRESSURE	180*	129,280	12	15,514
PROFILE	350**	263,340	12	31,600
SHEET	38*	41,590	12	4,990
SIDING	35*	47,890	12	5,747
FILAMENT WINDING	25*	12,830	10	1,283
FOAM				
TRAYS	18*	24,630	12	2,956
SHAPES	18*	24,630	10	2,463
INJECTION				
REACTION	36*	35,700	20	7,140
THERMOPLASTIC	4800***	3,283,200	20	656,640
THERMOSET	22*	22,570	20	4,514
REINFORCED		208,620	10	20,862
ROTATIONAL				
OVEN	45*	10,780	10	1,078
OPEN FLAME	37*	8,860	10	886

POTENTIAL ELECTRIC ENERGY SAVINGS USING PROCEDURAL METHODS WITH NO CAPITAL EXPENDITURE OR CAPITAL EXPENDITURE WITH LESS THAN 2 YEARS PAYBACK (cont'd)

STRUCTURAL FOAM	15*	16,420	15	2,463
VACUUMFORM	120*	102,600	15	15,390
WIRE & CABLE	180*	246,240	10	24,624
MISCELLANEOUS INCLUDING FABRICATION		114,000	10	11,400
	TOTAL	5,875,260	TOTAL	998,634
		GIGAJOULES (10^9)		GIGAJOULES (10^9)

NOTE 1. The estimated accuracy range of the actual number of major processing machines in Canada is indicated below.

* Within 5% accuracy

** Within 10% accuracy

*** Within 15% accuracy

NOTE 2. The average % of savings for the total industry is 16.8%.

NOTE 3. Conversion factor used -1 kWh (kilowatt hour) = .0036 Gigajoules (10^9)

The 1980 Statistics Canada report indicated that electricity represented 38% of all energy used.[11] In some processes it can be much higher than this average for the industry. In a typical injection molding plant electric energy can account for 75% of the total energy used, or at the present rates, more than 85% of the cost.

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[11] Statistics Canada - Consumption of Purchased Fuel and Electricity Catalogue #57-208 1980 - Tabulated (not published) at completion date of this report)

The payback on the investment in these new technology advances, if based on energy conservation alone, would be too long to be practical for most processors. However, in many cases the new technology will bring considerable improvement in productivy. And this is where productivity and energy conservation go hand in hand. Again this will be discussed in the section on new equipment.

In assessing the potential energy saving over the next few years, it is important to estimate the updating of manufacturing equipment and how this will contribute to the conservation program.

It is certainly not realistic to expect the Canadian Plastic Processing Industry to suddenly replace all of its equipment even though the improved productivity brings a reasonable payback. It has never happened that way in the past and there probably will not be a drastic change in concept that will mean such a huge capital investment. The need is certainly there to upgrade equipment in the Canadian industry if it is to be competetive on world markets. The pattern will probably be somewhat slow replacement over the next 5 to 7 years.

Where expansion is taking place a firm buying additional equipment will have an opportunity to take advantage of the newer technology. This may spur the replacement situation when people see the surprising improvements in productivity possible with the new machines and process controls.

Combining the direct energy savings possible from new equipment which is now available, and the energy saving inherent in improved productivity, there is no question that a saving of 20% is achievable as a conservation figure. If this equipment is acquired over the next 5 years, we can therefore estimate a long range saving of 4% the first year, 8% by the end of the second year, 12% by the end of the third year and so on. Keep in mind this is additional to the estimated procedural savings covered in the previous section.

Converting this to Gigajoules and using the second year figure so we can add the figures to the procedural savings, we come up with an annual figure for the second year of 470,020 Gigajoules. (10^9)

4.5 POTENTIAL ENERGY SAVINGS IN FUEL OIL

We discussed previously the 1980 Statistics Canada figures where nearly 20% of total energy use was fuel oils for building heat. We hoped this was on the down trend because of further conversions in 1981 and 1982. However, the limiting factor may be the lack of adequate natural gas distribution lines in some areas.

We believe this is particularily true in Quebec where there is a fairly large percentage (25.4%) of the plastic processing establishments, with many of them located in areas not serviced by natural gas.

However, even if these firms remain on fuel oil, they can conserve by reducing consumption. There is no question that with procedureal or housekeeping methods, and virtually no capital expenditure, they could attain a saving of 20% on an annual basis by the second year.

Based on a total industry estimated use of fuel oil in 1982, of 2,822,900 Gigajoules (10% lower than 1980), the 20% saving by 1984 would amount to 564,600 Gigajoules (10^9).

4.6 POTENTIAL ENERGY SAVING IN NATURAL GAS

Natural Gas is used in the Plastics Processing Industry to heat buildings such as manufacturing areas, warehouses and offices. It is also used extensively in the manufactureng process in some segments of the industry such as bottle blowing, film expanded bead and rotational molding.

As most firms do not meter the gas separately for building heat and process, it is impossible to accurately establish the energy saving potential in each area. In those firms with active conservation programs in place it would appear that a saving of 20% is possible in both the process and building heat energy consumption. As in the case of electric energy, this can be achieved through procedural methods or with capital expenditures with less than 2 years payback.

As it takes time to start successful programs, this level of saving would not be accomplished in the first year of operation, therefore, we are estimating an annual saving for the second year of 1,296,500 Gigajoules (10^9).

4.7 LONG RANGE POTENTIAL SAVINGS IN NATURAL GAS

There are a variety of available methods to conserve Natural Gas energy beyond the peocedural activities and short payback projects. These may range from 2 to 8 years payback. However, in today's economic conditions those with paybacks exceeding 2 years are not too likely to be pursued. Among these concepts would be building insulation, heat recovery systems and major process changes in those segments of the industry which use natural gas in their processes.

These items will be discussed later in this report in the section dealing with general energy conservation ideas. However, for the purpose of defining potential savings we will treat the estimates in the same way as electric energy when it comes to capital expenditures with longer than 2 years payback.

We will assume a reasonable amount of this type of investment takes place over the next five years. If in each year sufficient capital was invested to give a 5% energy saving, we could assume a 10% saving in the year 1984.
This saving would amount to 648,240 Gigajoules (10^9) for the year 1984.

4.8 A TARGET ENERGY SAVINGS POTENTIAL FOR 1984

We are assuming the industry can be activated to greater efforts in energy conservation. As mentioned previously, the greatest deterrent to more activity in this area, is the misconception that energy conservation is going to take a great deal of everyone's time plus a large capital investment. Also, many firms are giving energy conservation a low priority because of th relatively low cost of energy in Canada, and the small percentage that energy costs constitute compared to other manufacturing costs in this industry.

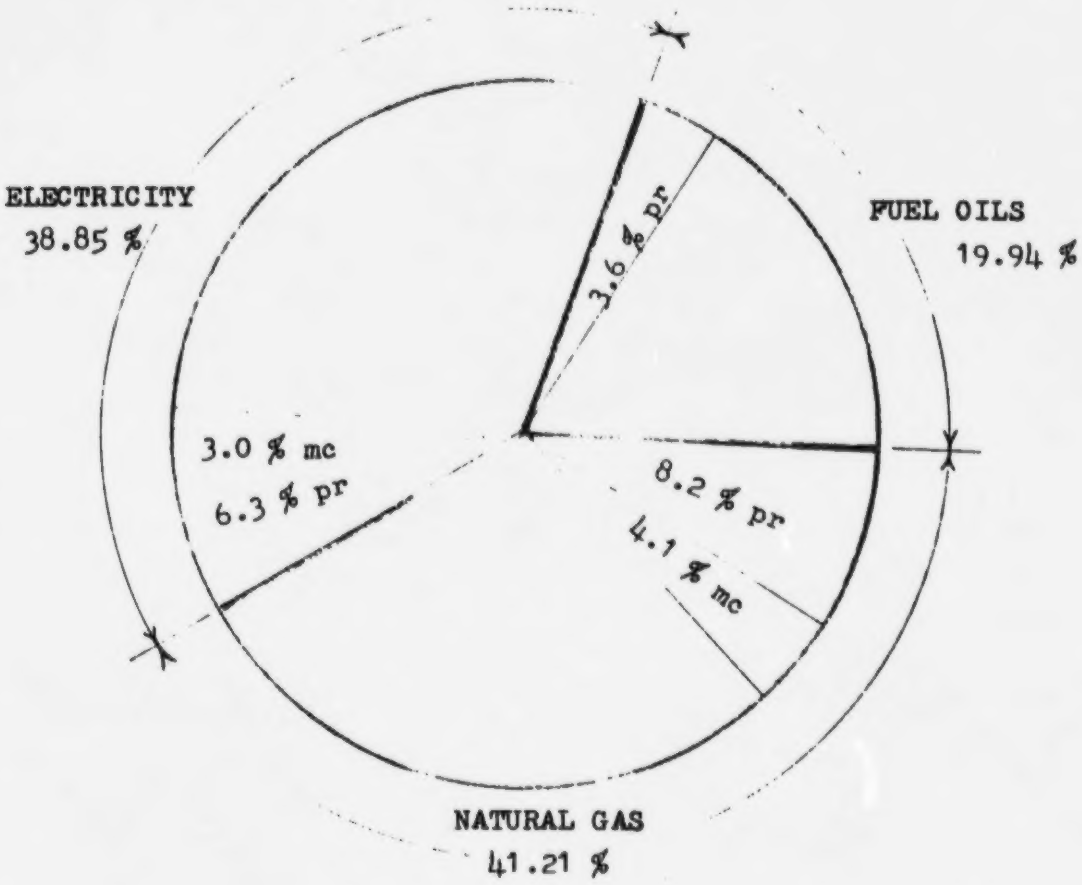
If the industry members can follow the example of those firms who have surprised themselves at how much money can be saved by operating energy conservation programs, the following targets for annual savings in 1984 could be reached.

May we stress these targets are not purely theoretical in any way. We believe they are conservative estimates and are proven by the examples discussed with firms presently operating programs.

TYPE OF ENERGY	POTENTIAL SAVINGS 1984 GIGAJOULES (10^9)	% SAVINGS COMPARED TO 1982 (EACH ENERGY TYPE)	% SAVINGS 1982 (TOTAL ENERGY ALL TYPES)
Electric (procedural)	998,634	16.8	6.3
Electric (capital)	470,020	8.0	3.0
Fuel Oils (including propane)	564,600	20.0	3.6
Natural Gas (procedural)	1,296,500	20.0	8.2
Natural Gas (capital)	648,240	10.0	4.1
TOTAL	3,977,994		25.2

It is a little difficult to relate the savings in Gigajoules to everday energy consumption. However, that saving would heat 30,933 average homes for a complete year in one of the normally cold areas in Canada.

TOTAL ENERGY CONSUMPTION (BY ENERGY TYPE) OF
PLASTICIC PROCESSING INDUSTRY 1980
and
ANNUAL ESTIMATED POTENTIAL SAVINGS FOR 1984
pr - procedural methods
mc - more capital methods
ESTIMATED COMBINED TOTAL POTENTIAL SAVINGS 25.2%



5. ENERGY CONSERVATION PROGRAMS (GENERAL COMMENTS)

The processors interviewed who were operating energy conservation programs were very willing to identify their successful methods and share them with the industry. They were extremely cooperative and gave generously of their time. We did discuss with two firms energy savings which came about by major process changes instigated to achieve economic advantages in their particular market. These must remain confidential but it shows there are sometimes very large energy savings possible by a major process, procedural or technical change.

The machinery manufacturers contributed heavily to possible procedural activities which would improve a processor's energy efficiency. This was over and above the technological improvements they are incorporating into their new equipment. The resin producers were able to add to this information.

A major objective of this study is to produce a document which can be used by processors in establishing or enlarging cost effective energy conservation programs in their operations. As a result of the survey, it became apparent a large majority of firms really had no program in place or such a casual program that it had little chance of being effective. Therefore, we believe it would be the best approach to start very simply and discuss energy saving procedures as though no programs existed. We would ask those processors who are operatin programs to bear with us but maybe even they will pick up some small item they have overlooked.

5.1. ESTABLISHING A PROGRAM

5.1.1 THE COMMITTEE

The inherent principle in any of the really successful programs we discussed during the interviews was that it should be formalized. This does not mean it need be fancy but it must be set up in such a way that everyone in the firm is aware a program is in existence. This also means that all employees recognize the interest and involvement of top management. For obvious reasons, if the employees believe top management thinks energy conservation is unimportant, the program will not have much chance of success.

Designated persons should be assigned to a committtee which should meet regularly in order to give focus to the whole program. Before anybody jumps to the wrong conclusion as to how much time this takes, we should point out that a formal meeting for one hour, once a month, will be sufficient to do the job. Minutes should be mainained in order to have a proper follow-up on the items and actions in progress.

The members of the committee will vary depending on the size of the firm. However, in principle, it should include top management (or representative), plant management, engineering, maintenance, foreman level and a representative from the operator level. These latter two would be best on a revolving basis. Smaller firms would have a smaller committee because one person is normally responsible for more than one of these functions. Try to include a person from accounting as this will be important once figures are needed to monitor the progress.

Regularity is the key to establishing energy conservation as a way of life. Meeting times should be set on a regular basis. At the beginning it will be difficult not to have these delayed or aborted because of other crises but it is important for everyone to realize these meetings should not be considered bottom priority.

Format of the meetings can be anything that seems to fit the operation and the people involved. It should be made clear to all employees of the firm that the committee is only the focal point of the program. Everyone should be encouraged to contribute ideas through the committee members. The revolving members from the employee group serve an important function in this regard. Some firms favour a reward system for ideas but be careful of this procedure. It is most difficult to administer and unless it is done very carefully, it can cause dissension.

Experts or specialists in specific areas can be invited to attend certain meetings or can be assigned projects on behalf of the committee. These can be internal staff or from outside sources. Many firms such as energy source companies or equipment manufacturers of all types can be very useful.

5.1.2 PERFORMANCE MEASUREMENT

The second key to establishing a successful program is to determine how performance is to be measured. This is absolutely essential, as otherwise, everyone will lose interest and the program will flounder.

The basic principle is to establish an energy use per unit of production. This sounds easy but in some operations gets rather difficult. Obtaining the energy consumption is the easy part. We would recommend having someone take five minutes each week, at the same time, and read the electric, gas, steam and water meters. If fuel oil or propane is used, this will need a different system. The meter readings can be recorded on a simple chart. The weekly habit is much better than relying on the monthly billings. The utility companies don't always read the meters on the same day of the month and have been known to estimate, knowing they would correct on the next reading. The whole purpose of this is to lock the consumption and the production unit into the same time frame. It is true this can be done on a monthly basis but the weekly approach will produce valuable information and will more likely lead to investigations quickly when something seems to be going wrong.

Some firms will have difficulty choosing a unit of production which they consider appropriate. Because of product mix, there will always be some weakness in whatever is chosen. People with dedicated lines should not have any difficulty. Unless you are producing similar units throughout your production, you will probably have to settle for kilos processed, or in some processes, a linear measurement will be suitable.

Don't worry too much about the flaws you perceive in the unit of production you choose. Once the base for comparison has been established and unless there is a drastic product mix change, the ups and downs will smooth out over a longer time frame. It is definitely a prime requirement of a successful program to be able to monitor your energy cost in relation to some unit of production.

5.1.3 ASSISTANCE IN ESTABLISHING A PROGRAM

There has been excellent literature produced by the Energy Conservation Branch of the Department of Energy, Mines and Resources. One of the most helpful aids in starting a program would be to obtain their INDUSTRIAL ENERGY CONSERVATION HANDBOOK. There are 11 brochures altogether in a loose leaf binder. The first booklet will be most helpful in the early stages of establishing your program. It is entitled FIRST STEPS TO ENERGY CONSERVATION FOR BUSINESS. The other 10 brochures cover specific areas of conservation.

These books are an excellent guide to use during your meetings, as they will spark ideas, especially until people are fully involved in the program. Some firms feel it is worth the expense to have a handbook for each person on the committee.

They are available from:

DEPARTMENT OF ENERGY, MINES AND RESOURCES
OFFICE OF ENERGY CONSERVATION
580 BOOTH STREET
OTTAWA, ONTARIO
K1A 0E4.

There are other sources of assistance who offer their services free of charge and who can be extremely helpful. The utilities in most areas will be glad to assist. For instance, Ontario Hydro has an Energy Conservation Division which can be contacted at the following address:

ENERGY CONSERVATION AND UTILIZATION DIVISION
ONTARIO HYDRO
620 UNIVERSITY AVENUE
TORONTO, ONTARIO
M5G 1X6.

Obviously the local utility companies will get involved at your request and there are similar energy conservation departments in many of the provinces.

Sometimes a consultant can be the catalyst to get a program going. There are advantages and also disadvantages to this kind of assistance. Probably the greatest advantage is that someone from outside of the organization will spot things that have become embedded in the procedures and the employees have come to accept them as the only way. In other words a consultant will ask a lot of embarrassing questions as to why things are being done in a certain way.

The disadvantage of a consultant is the tendency for the members of the company operating team to expect him to solve all the problems on an ongoing basis. The consultant is there to point the way and company personnel must still be heavily involved and ultimately carry the burden themselves.

The best chance of success, regardless of which route is chosen, is to capture everyone's interest and let them share the involvement of the accomplishments as the program progresses.

6. ENERGY CONSERVATION TECHNIQUES

6.1 GETTING THE PROGRAM ACTIVATED

At first the committee will be uncertain where to start. One good method is to use some presently published literature which can act as check list of items to discuss and investigate. The previously mentioned Industrial Energy Conservation Handbook published by Energy, Mines and Resources is very good for this purpose.

Another good guide to spark ideas is REDUCING ENERGY COSTS IN THE PLASTIC INDUSTRY published by The Society of the Plastics Industry Inc., N.Y., U.S.A. This is available from SPl in Canada. You can write to:

THE SOCIETY OF THE PLASTICS INDUSTRY OF CANADA
1262 DON MILLS ROAD
DON MILLS, ONTARIO
M3B 2W7

The best advice, considering the small size of most of the processors, is to keep the whole program very simple. If the committee brainstorms for the first frew meetings, there will soon evolve a list of situations to investigate. Once these get underway further suggestions will be generated.

It is important at this stage to closely monitor the results where possible and publicize the activities to the whole firm. Individual successes and case histories are valuable in getting everyone to realize the program in worthwhile. Always report in dollars saved as well as percentages and energy units, so people can relate the results in easy terms.

These first months will be difficult, but as soon as some positive results are developed, everyone will be surprised at how many more things will evolve as people get in the habit of being energy conscious.

An excellent attention getter at this stage of the program, is to arrange for an ENERGY BUS AUDIT. At the present stage nearly every province has one or more buses operating. To arrange for an audit, contact your nearest Industry and Trade office where you will receive application forms. The buses are usually very busy so be prepared for a wait before the bus can actually visit your plant.

The bus is equipped with a computer and staffed with an engineer and two computer operators. They also carry heat-loss measuring devices as well as energy conservation demonstration equipment.

After the audit, the computer print-out is produced immediately and is discussed with the energy management team of the company. The print-out can then be used to guide the energy conservation committee in their program.

In the early stages of the program, this audit was inclined to concentrate on major items which required large capital expenditures. Smaller firms could not manage the long pay-backs and thus did not take much action. However, the present method of audit and the personnel involved make it possible to look at procedural activities as well as building and the whole program becomes more effective. So if you used this audit 2 or 3 years ago, we suggest you arrange for a new audit which could prove very helpful.

6.2 AREAS FOR INVESTIGATION COMMON TO ALL PLANTS

Before we discuss energy saving potential in individual processes, there are a great number of items common to all plants which can be investigated. Many of these are ideal for the new program for several reasons. they are areas visible to all employees and everyone can see something happening. They are also areas that will bring good results with little or no capital expenditure.

At this phase equip the committee with another publication that is available.

ENERGY CONSERVATION SOURCE BOOK
MODERN POWER AND ENGINEERING
MACLEAN-HUNTER LIMITED
481 UNIVERSITY AVENUE
TORONTO, CANADA
M5W 1A7

This issue, sponsored by Ontario Ministry of Industry and Tourism, not only lists sources of energy related equipment but also gives case histories and areas of possible conservation.

A partial list of areas for investigation follows:

6.2.1 LIGHTING

A general audit of the lighting will disclose areas of inefficiency. These include excess lighting which can be reduced by removing some fixtures or relocating them to better advantage.

In some areas such as warehouses the lighting can be turned off if the area is used intermittently. If this cannot be accomplished successfully manually, equip the area with automatic controls.

Investigate the pay-back on using watt-saver flourescent, mercury vapour or high pressure sodium.

These procedures are covered in greater detail in the SPI book previously mentioned, titled, REDUCING ENERGY COSTS IN THE PLASTIC INDUSTRY. (The Society of the Plastics Industry Inc., N.Y. U.S.A.).

RECOMMENDED LIGHTING LEVELS (*)

Task or Area	Footcandle Levels	How Measured
Hallways or corridors, storage areas.	15	Measured average, 3 feet from floor
Circulation areas surrounding machinery, active stockrooms, shipping areas.	30	Measured average, 3 feet from floor
Normal office work, inspection areas.	50	Measured at work station
Prolonged office work which is visually difficult, task lighting levels for sorting and difficult inspection, operation of most molding equipment.	75	Measured at work station
Operation of dangerous machinery, tool and mold making task lighting, inspection requiring detection of very minor flaws.	100-200	Measured at work station

LIGHTING EFFICIENCY OF DIFFERENT TYPES OF LAMPS (*)

Lamp Type	Lumens per Watt Efficiency
Incandescent (quartz also)	17 - 24
Mercury Vapor	30 - 60
Fluorescent	75 - 85
Metal Halide	80 - 115
High Pressure Sodium	70 - 140
Low Pressure Sodium	120 - 150

ENERGY SAVINGS FROM RELAMPING (*)

Replace	With	And Save (watts/lamp)	Annual $ Savings per lamp*
4-foot fluorescent	4-foot energy-saving equivalent	7	$ 0.73
8-foot fluorescent	8-foot energy-saving equivalent	12	1.25
8-foot high-output fluorescent	8-foot high output energy-saving equiv.	15	1.56
40-watt incandescent	36-watt, equivalent light output	4	0.42
75-watt incandescent	69-watt, equivalent light output	6	0.62
150-watt incandescent	143-watt, equivalent light output	7	0.73
150-watt reflector flood lamp	75-watt elliptical reflector (ER) flood lamp	75	7.80
300-watt reflector flood lamp	120-watt elliptical reflector	180	18.72

*Assumes eight hours daily operation at $0.05 per KWH.

(*) Reducing Energy Costs in the Plastics Industry
The Society of the Plastics Industry Inc. N.Y. U.S.A.

6.2.2 HEATING AND AIR CONDITIONING

A general audit of the building condition is a good place to start. Seal areas of draft such as doors, windows and expecially shipping dock arrangements.

Control the heating and cooling levels of offices, warehouses and work areas. This is best done by automatic thermostats for set-back at night and weekends. It will probably be necassary to have these locked to avoid tampering.

Insulate steam pipes and hot water pipes.

Check the boiler or furnace efficiency. Maintenance is extremely important and can produce impressive energy savings. Investigate stack economizers.

Getting into areas of longer pay-back, insulating building walls and roof can save a great deal of energy if the building is an older structure with a lot of metal frame windows.

Areas of heat transfer can be very productive. Much of this can be done with little expense when process heat can be moved to warehouse areas. Heat trapped at the ceiling can be utilized by slow moving ceiling fans.

Longer pay-back capital expenditure items but well worth investigating, are other means of heat transfer such as heat pupms, heat exchangers of various kinds and heat pipes. Depending on the circumstances, all of these do an excellent job of recapturing lost heat energy. Pay-back would have to be determined for particular application.

Detailed articles on this subject are reprinted in APPENDIX F.1.

6.2.3 COMPRESSED AIR SYSTEMS

Make sure the compressor is using an exterior intake. A compressor operates more efficiently on cool air and in many cases the compressor is located in an area where the room temperature is high.

Check the system for air leaks. These can occur at hose connections, nozzles, valves or from worn cylinders. Finding a 20% loss is not uncommon but close control can reduce this to 2%.

Using a piece of copper pipe as a nozzle is extremely wasteful of compressed air. Investigate the enginerred nozzles available as they have a very fast pay-back.

Keep the pressure in the system as low as possible. This not only reduces the compressor operating cost but helps reduce the leak problem.

Capture the heat from the compressor and utilize it by heat transfer to another area.

6.2.4 MAINTENANCE

Obviously maintenance of plant and equipment can be a major factor in energy conservation. It has already been touched on in connection with the areas already discussed. It will also be covered in the specific process sections where poor maintenance can produce a higher energy cost per unit of production.

A detailed article specifically on maintenance as related to energy conservation is contained in APPENDIX F.2.

An excellent instrument for maintenance use is a non-contact heat sensing device for checking hot spots in power lines and bus ducts and also useful in checking for overheating motors. This instrument can be used for any situation where it is useful to monitor heat changes as a possible energy loss. A sheet is included in APPENDIX F.2. illustrating one of the models available.

6.2.5 ELECTRIC LOAD DEMAND CHARGES

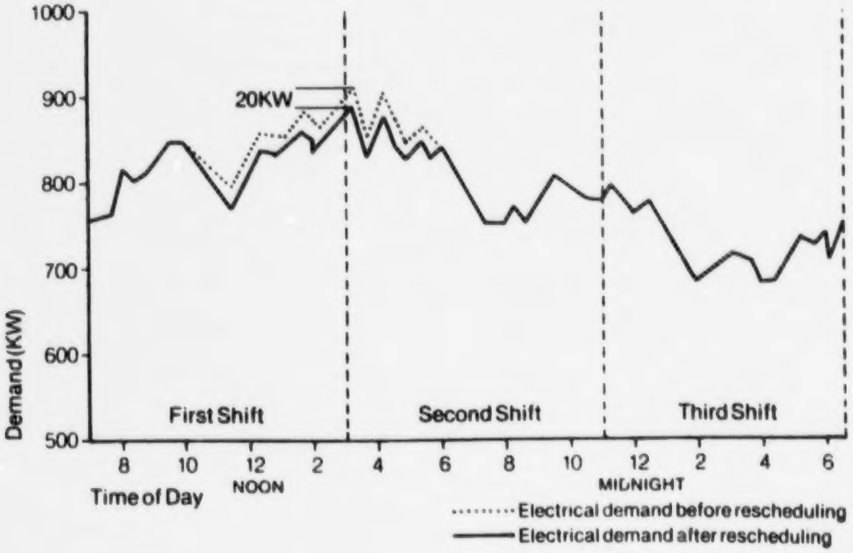
As such a large percentage of energy consumption in Plastics Processing is electricity, it is important that the committee spend considerable time investigating this area. There are several ways money can be saved even when using the same amount of electricity.

Utility companies charge a basic amount for the actual energy used but on top of this they also assess a "demand" charge. This is based on the peak reached in a given period on the theory they are required to hold this in reserve for the customer. In different provinces this is handled in a different way and in some cases the contracted peak can be the chargeable rate for long periods. make sure the method in your area is well understood by the committee.

Regardless of the system, it is important to minimize the demand charges by smoothing out the peaks. If possible, borrow or rent a graph meter for your power lines and establish your pattern over several months.

Once you know your pattern, it is possible to schedule or control the use of equipment in order to spread the load more evenly. Some possible improvements will come from stagerred start-ups and from cycling some equipment such as grinders, dryers, ovens, air conditioners and auxiliary equipment of all kinds.

A TYPICAL DAILY ELECTRIC DEMAND FOR A MOLDING PLANT (*)



ELECTRIC LOAD POWER FACTOR

Power Factor is another area to investigate. In most areas, the utility company will charge a penalty if the power factor is lower than 90%. To correct this it is necessary to add further capacitors either at the central bank of incoming power or at individual machines.

There are normal capacitors which are installed on a permanent load capacity basis, but there are also automatic correction systems (now available). Obviously pay-back will have to be checked out in each case and diagnosis made by professionals to make sure the system being contemplated is the best for your needs.

(*) Reducing Energy Costs in the Plastics Industry
The Society of the Plastics Industry Inc. N.Y. U.S.A.

A brochure from one of the available automatic systems is included in APPENDIX F.3.

ELECTRIC LOAD MANAGEMENT SYSTEMS

Various controls can be purchased to assist in handling the electric power load. These will have to be checked against cost savings depending on the size of operation.

In discussing demand charges earlier, we pointed out the penalty for high peak demands. Other than scheduling control, this situation can be improved by load shedding devices. This equipment is available from relatively inexpensive units to handle only load shedding, up to microprocess controllers which will handle several other functions.

A load shedder is used to shut down designated equipment within the allowed 20 minutes in order to avoid such a high peak. For instance auxiliary machines such as grinders, ovens or chillers could be shut down temporarily until they can be brought back without causing a new peak.

The more expensive microprocess units can load shed in a more sophisticated manner by prioritizing a group of machines so they will shut down in sequence as needed to avoid the peak. This equipment can also be used to "duty cycle" groups of machines to avoid having them all on at once. For instance, a group of air conditioners can by cycled in sequence which not only saves the peaking situation but actually cuts down on basic energy used. A load management controller can also be used to fine tune the start-up procedures by turning the heats on machines at the exact time determined to be the minimum necessity. Of course it can also handle the automatic lights and thermostat control otherwise handled by individual timers.

Two of the available systems are illustrated in APPENDIX F.3.

ELECTRIC LOAD MOTORS

There has been considerable discussion on ENERGY EFFICIENT MOTORS. This is a major subject for any energy conservation committee because electricity for motor use is by far the largest consumer of electricity in industry. Ontario Hydro in the chart below state 76.1% of all electricity used by industry is for motors. (*)

Industrial Motor Uses:

- pumps
- compressors
- fans
- conveyors

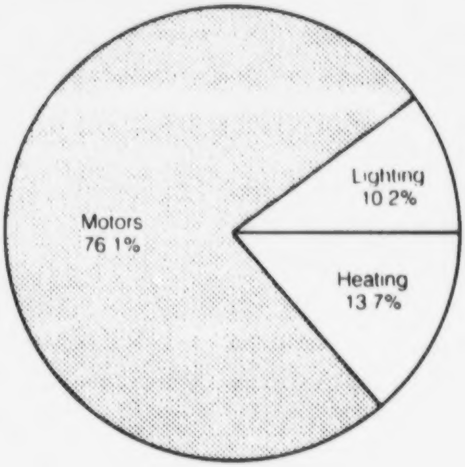


Figure 2.4
Distribution of Industrial Electricity Use
30.6 Billion kW·h

(*) Energy Efficient Motors
Energy Conservation and Utilization Divison
Ontario Hydro Toronto February 1981

Advantages for "energy efficient" motors have been cited as follows (*)

- reduction of operating costs.
- reduced internal heat and therefore longer life.
- reduction of power factor penalties.
- less loading on feeder circuits and transformers.
- reduction of capacitors.

In their ENERGY EFFICIENT MOTORS brochure, Ontario Hydro show case histories to prove that these motors are cost effective in absorbing their higher initial cost. (*) This is for purchase of a new motor or replacement of a defective worn out motor. However, they point out that replacement for energy considerations alone probably would have too slow a pay-back to be of interest. Some specific cases of replacement have been cost effective so pay-back calculations should be made if you believe you have motors in borderline situations for replacement.

Portions of Ontario Hydro's brochure ENERGY EFFICIENT MOTORS, is reporduced in APPENDIX F.4.

7. ENERGY SAVING IN INJECTION MOLDING

By our estimates of the energy consumption of the Plastics Processing Industry in Canada, we found that injection molding machines use 55% of the total electric energy used by processors in this country. We also found that because of the actions necessary in this type of machine, heavy energy requirements are unavoidable. However, the disturbing part of all this is that machines in the past have been relatively energy inefficient in design and processors have not used their machines to the best efficiency advantage when it came to energy consumption.

(*) Energy Efficient Motors
Energy Conservation and Utilization Division
Ontario Hydor Toronto February 1981

The plastic process machinery manufacturers are making large design changes to make equipment energy efficient. The molders can improve their operating procedures once they understand the economic advantages of energy considerations, which also means an additional gain in productivity in many cases.

As most injection molders use natural gas and fuel oil for building heat only, this section will deal exclusively with electric energy. We have already covered the energy conservation methods for natural gas and feul oil in the general section on HEATING.

7.1 INJECTION MOLDING MACHINES

By far the largest use of energy in an injection molding plant is the injection machines themselves. We will concentrate our attention here for this first section. To illustrate just how much the machines themselves use, in relation to the rest of the plant we submit the following figures:

CALCULATION FOR SUBSTATION REQUIREMENTS FOR OPERATING 10 INJECTION MOLDING MACHINES (*)

PLANT EQUIPMENT	MAXIMUM EXPECTED DEMAND, KVA
Injection Molding Machines	950
Raw Material Handling	11
Chillers	80
Cooling Tower	30
Air Compressors	52
Plant Lighting	60
Ventilation	3
Air Conditioning	96
Mold Maintenance	50
Machine Maintenance	50
Secondary Operations	25
Offices	50
TOTAL	1457

NOTE - The molding machines account for 65% of total demand.

Our estimates made earlier in this study, stated electric energy savings in injection molding was 20% on a procedural bases and a further 8% by the second year of equipment improvement by capital investment. We also stated this to be a conservative estimate in our opinion. This statement was made knowing the estimates in other more technical studies.

(*) Energy Considerations in Planning an Injection Molding Operation-Rodolfo Selem-Systems Engineer-Husky Injection Molding Systems Ltd., Modern Plastics September 1982

For instance, the Institute for Plastics Processing in Germany, INSTITUT fur KUNSTSTOFFVERARBEITUNG (IKV) in Aachen has done detailed studies on the subject and has published the following estimates.

A HYPOTHETICAL LIST OF ENERGY SAVINGS WITH
MODERN EQUIPMENT IN EXISTING OPERATIONS.(*)

Efficient start-up	4%
Optimum hydraulics	13%
Pressure savings (example use of accumulators)	8%
Compatible screw drive to hydraulic system	4%
Insulated injected unit	2%
Insulation on molds	2%
Optimum mold layout	2%
Optimum operating	5%
TOTAL	40% Savings

This estimate shows that 25% involves having modern equipment incorporating the latest energy efficient engineering designs. However, the rest is something the processors can do for themselves. It is a significant amount and well worth working on in any energy conservation program.

7.2 PROCEDURAL ENERGY SAVING TECHNIQUES

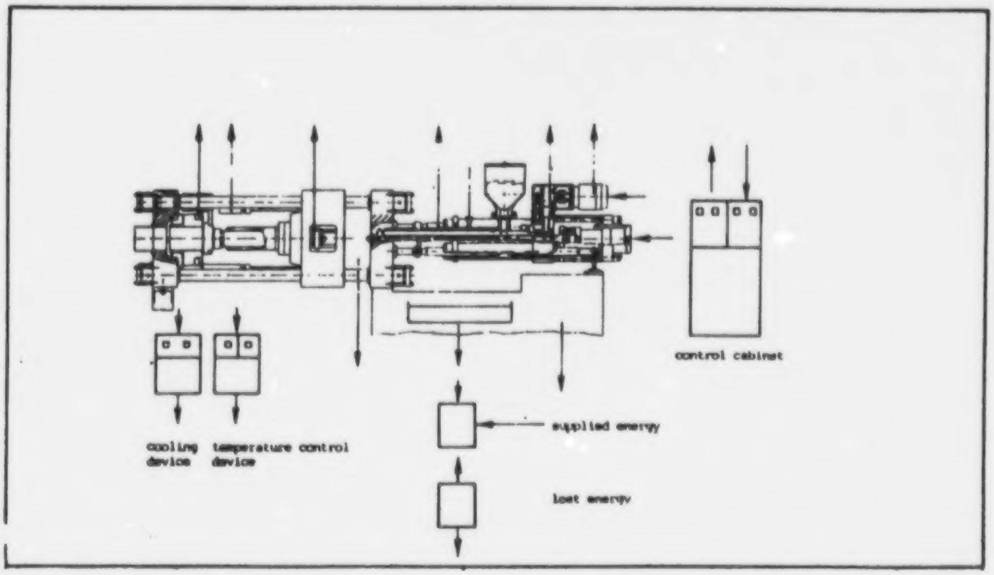
Each of the procedural items which reduce energy consumption

(*) Energiefluss und - einsparung an Maschine und Werkzeug
(Energy Flow and Energy Savings on Machines and Molds)
Jurgen Rothe - Institut fur Kunststoffeverarbeitung (IKV)
Aechen, Federal Republic of Germany

may in themselves only account for a small saving but the combined totals can be impressive. In Many cases it is a matter of cleaning up old bad habits evolving from times when energy was less expensive. A lot of these are involved in start-up and set-up. A few examples to work on are as follows:

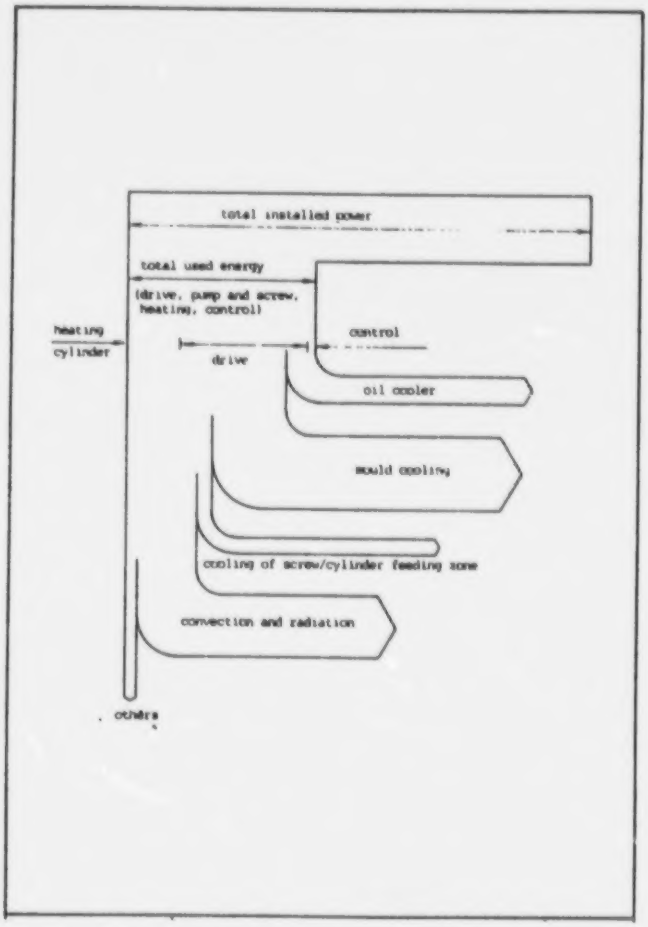
- minimize warm-up time in starting the initial shift.
- try not to have back-up machines warming up too soon.
- set stroke to minimum necessary for part release.
- set clamp to minimum for particular mold in machine.
- set screw speeds to minimum within lowest cycle.
- Keep lowest practical temperature while attaining good quality melt.
- Use as little back pressure as possible.
- select injection sequence for lowest energy use but maintaining productivity and quality levels.
- on older hydraulic machines without micorprocess controls set the low pressure controls to activate after injection cycle.
- make sure heats are correct for the resin being used.

The following diagram shows the supplied and lost energy in the injection molding process. (*)


control cabinet
cooling device
temperature control device
supplied energy
lost energy

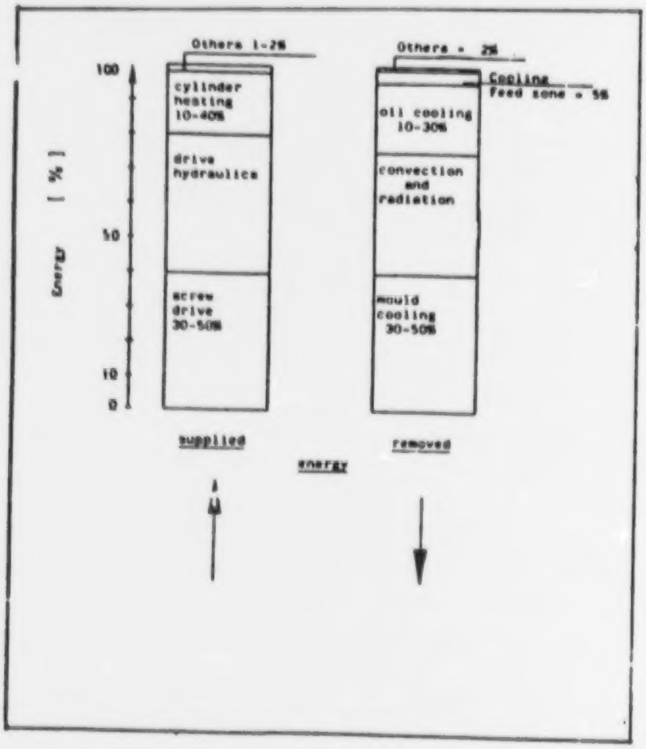
(*) Dipl.-Ing Helmut Eckardt
Battenfeld Maschinenfabriken Gmbh. Meinerzhagen
Federal Republic of Germany

The Sankey Diagram below shows the used energy and the lost energy during the injection molding process. (*)


total installed power
total used energy
(drive, pump and screw, heating, control)
heating cylinder
control
drive
oil cooler
mould cooling
cooling of screw/cylinder feeding zone
convection and radiation
others

(*) Dipl. - Ing Helmut Eckark
Battenfeld Maschinenfabriken Gmbh. Meinerzhagen
Federal Republic of Germany

This diagram shows the percentages of total energy supplied to operate the molding machine and also the percentages of energy used for cooling and lost to convection and radiation. (*)



(*) Dipl.-Ing Helmut Eckardt
Battenfeld Maschinenfabriken Gmbh. Meinerzhagen
Federal Republic of Germany

These illustrations will assist the committee in understanding the energy use of the injection machine and concentrate efforts where they will be most productive.

One of the procedures to avoid is operating equipment substantially below capacity. The hydraulics cannot operate efficiently and the penalty on energy consumption is high. The type of resin also makes considerable difference to the energy consumption and both of these situations are illustrated below. (*)

SPECIFIC ENERGY CONSUMPTION AS A FUNCTION OF RAW MATERIAL AND OF UTILISATION OF THE MAXIMUM SHOT WEIGHT

Moulding	Weight	Raw material	Cycle time	Type of machine	Utilisation of maximum shot weight	Drive + plasticisation	Heating	Total
/	g	/	s	/	%	kWh/kg	kWh/kg	kWh/kg
Flowerpot, 1100	14.5	Polyethylene	3.05	170/85 HK ES	18	0.9186	0.1402	1.0588
Lid for bucket	50.8	Polyethylene	6.6	300/100 HK ES	42	0.4047	0.07475	0.47945
10 l bucket	610	Polyethylene	25	3200/500 S	58	0.4030	0.1434	0.5464
12 x 1 l bottle crate	1900	High density polyethylene	50	5000/650 S KS	67	0.2846	0.0842	0.3688
Large trough	3500	High density polyethylene	210	12500/-1500 S DS	59	0.41	0.32	0.73
Herring pot	21.6	Polypropylene	5.8	300/70 HK KS	15	0.6444	0.3032	0.9476
Box 1 l	43	Polypropylene	6.4	300/100 HK ES	30	0.6102	0.2233	0.8335
Chair	1765	Polypropylene	83.9	8000/850 S KS	45	0.3272	0.1874	0.5146

Finally on procedures, it is quite effective to insulate the barrel of the machine. This saves energy on warm-up as well as during processing. A shield is common on most machines but further insulation will improve the situation. The problem is to devise an adequate insulated cover without having it be a hindrance inb set-up and operating. Some of the equipment manufacturers are working with some practical designs.

(*) Dipl.-Ing Helmut Eckardt
Battenfeld Maschinenfabriken Gmbh. Meinerzhagen
Federal Republic of Germany

The small chart below shows the results in energy saving during warm-up with an insulated cover. (*)

ENERGY CONSUMPTION FOR HEATING THE SCREW CYLINDER (BSKM 500/220 S 60 B)

Time from start of heating-up	without with insulation of the screw cylinder		Saving through cylinder insulation
min	kWh	kWh	%
30 min	4.8	4.2	12.5
60 min	6.0	5.4	10.0

There are a number of excellent articles on the above subject. Most molders have not been energy conscious over the past years, and have failed to realize how improving a number of these procedural habits, can lead to considerable economic advantage. In striving for productivity only, they have missed the point that often they can have both energy efficiency and productivity. In some cases it can lead to improved productivity.

To study these procedures in greater detail, please refer to APPENDIX G.1. where 3 articles on the subject are reprinted in entirity.

7.3 MOLD ORIENTED ENERGY SAVINGS

The mold and its condition can contribute to waste energy and therefore is a subject for energy conservation committee investigation. In general some areas to look at are as follows:

- mold condition-if it will not seal off, energy is wasted by higher clamp pressures (as well as waste materials).

(*) Dipl.-Ing Helmut Eckardt
Battenfeld Maschinenfabriken Gmbh. Meinerzhagen Federal Republic of Germany

- check gating techniques for lowest possible pressure requirements consistent with other job needs.
- check for most efficient cooling at minimum energy cost.
- mold design can drastically effect productivity and therefore energy consumption.
- some mold design such as stack molds can be used on many products to increase productivity at less energy cost.
- runnerless molds save energy as the material in the runners does not have to be processed and then reclaimed.
- on some resins molded at high temperatures it will save energy to insulate the molds.

7.4 RESIN ORIENTED ENERGY SAVINGS

- the development of high flow resins has contributed to energy savings as they can be processed at lower temperatures.
- correct molding temperatures will save energy in several ways.
    - lower processing heat means less cooling.
    - less flashing and packing saves material and energy.
- choice of resin for moldability in the particular mold.
- glass filled resins take less energy to plasticize.
- mineral fillers are also an energy saver.
- resins with better moldability have improved cycles which increase productivity and thus save energy.

7.5 THE NEW BREED OF ENERGY EFFICIENT INJECTION MACHINES

The machinery manufacturers have worked hard over the last few years to improve the energy efficiency of their equipment. This has been discouraging for them as most equipment buyers have not given energy considerations high priority at time of purchase. This is particularily true in Canada because of our relatively low energy costs. In comparison, energy costs in the U.S.A. vary widely and in some areas are nearly 3 times the cost in Canada. This also applies in Europe. In Japan it is even worse as in some areas energy costs can be 8 times more than in Canada.

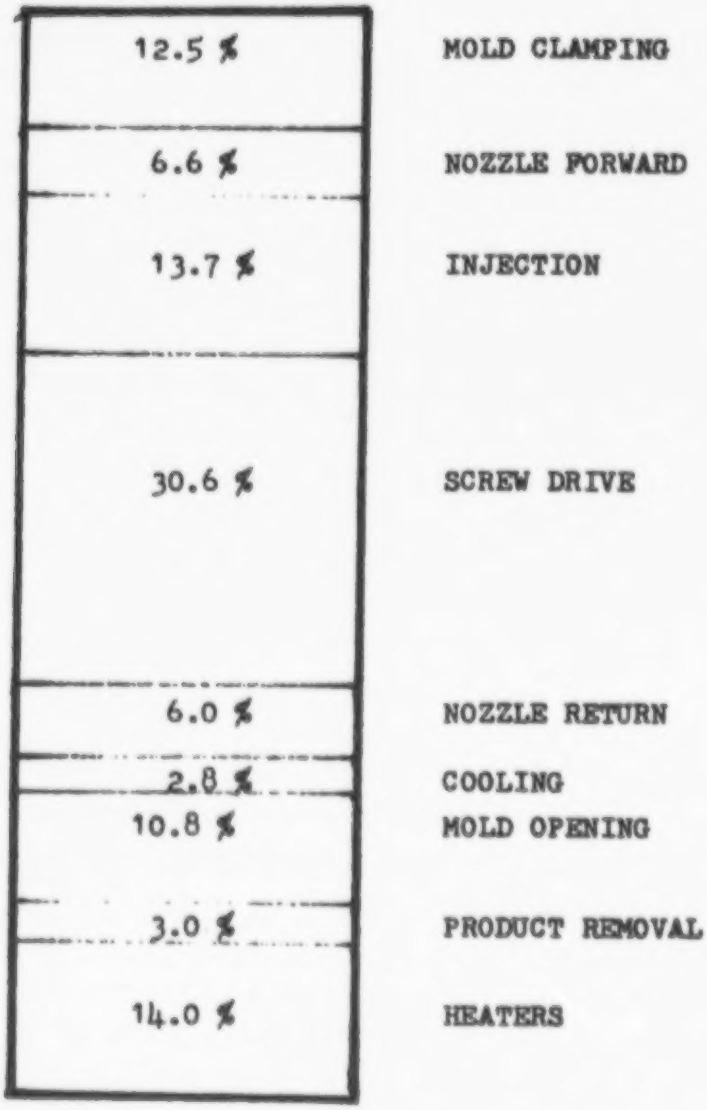
Thus the machinery manufacturers in these areas have been very conscious of the need for improvement. The difference between the theoretical energy needs and the actual energy consumed is dramatic. Some people rate the older injection machines as being no more than 15% energy efficient.

In making their improvements, the machinery manufacturers have found great difficulty in finding a common ground for measuring energy efficiency. It is extremely difficult to test different makes and sizes of machines under the same molding conditions. The need is for a standard test method and it appears to be on its way. The manufacturers have a test method under review at the present time and hopefully an SPI standard test will be available in 1983.

In the meantime, it is hard for a prospective buyer to assess the energy conservation ratings of the various machines. They are usually stated in percentages based on comparative machines; but in most cases the tests are qualified because of possible differences in machines or molds used in the test.

All manufacturers agree that the hydraulic pumps consume the largest share of energy. The percentage will vary from machine to machine but an average figure would be approximately 70% with the heaters taking the balance of 30%

Splitting this into separate functions shows the following energy use percentages.(*)



(*) Energy Saving Injection Molding Machine SSE System
Nissei Plastic Industrial Col Lt d. Sakaki, Nagano-Ken, Japan

Recognizing the large energy use of the pump system and also recognizing that in the older machines this is the area of greatest energy inefficiency, the manufacturers have concentrated their design changes around this function of the machine. What has evolved is a variation of design, depending on each manufacturer's own concepts as how best to achieve energy efficiency.

Some manufacturers have gone the variable displacement pump route. Some have gone for multiple pumps controlled by microprocessors. Others have tried to reduce the volume of oil needed and still others have gone for combinations. Certainly this report cannot sort out the various claims made for each system. But it is enough to point out that if you are about to buy a machine, it would pay to look thoroughly at the tremendous progress that has been made in machine design recently, in regard to energy efficiency.

We felt it would be of assistance to include a number of excellent articles on the subject and these can be referred to in APPENDIX G.2.

One of the largest energy wasters, involves the use of injection machines at much below their capacity. this has partly come about by the buying habits of molders in the past. Unless a firm was buying a machine for a dedicated line, the tendency was, for very little more expense, to size up or add extras "in case they might be needed tomorrow".

The energy penalty for operating at lower than 75% of pump capacity is severe. The manufacturers are trying to build in more flexibility (without energy cost penalty) but the best advice in purchasing, is to resist the temptation to insure against all unknowns and try to match the machine to what you expect it will be molding 90% of the time.

The machinery manufacturers also suggest that many molders do not optimize the operation of the machines they buy. Plant personnel are prone to operate a new machine much the same as their old one, and thus never really cash in on the new technology they have purchased.

In the past, machinery manufacturers overpowered much of their equipment. As a selling feature this was impressive. They are now reversing this trend and you will find power reduced and energy more efficiently utilized.

If you mold much hydroscopic material which needs drying, you will find a vented barrel is cost effective if you purchase it on the original equipment.

Finally, work closely with your machinery supplier and make sure your needs are well understood. In this way the equipment can be optimized for the most efficient productivity and energy conservation results.

7.6 SCREW DESIGN AND MAINTENANCE

Not nearly enough attention is paid to the screw feed of the injection molding machine. We saw by the earlier diagram that screw drive can consume 30% of the total required energy. The situation can be much more serious if the productivity is also effected.

Firms who run dedicated lines usually have a screw designed for their particular requirement in resin and product. Thus they optimize energy efficiency and productivity. They also are more inclined to keep their screw and barrel in top condition.

However, by far the greatest number of injection machines in Canada, are expected to mold many different products and different types of resins. This means a universal screw and this means compromise. Recognizing this, there is still much a molder can do to help both productivity and energy efficiency.

- pick a screw to match the highest percentage of expected production.
- check new screw design developments as much has happened in the last couple of years.
- check the screw and barrel wear every 5 to 6 months at the longest. Don't just ram more speed and power to it to make up for the slippage as this is very costly.
- replace or repair worn screws as the pay-back is fast.

- be prepared to change the screw for a particular run if the run is sufficiently long.

For articles in greater detail, on both screw efficiency and screw wear, please refer to APPENDIX H.1.

7.7 HEATER BANDS

There has been a continuing controversy over the last two years on the most energy economic type of heater band for injection molding machines. At the time of this report, no clear-cut answers have emerged.

The controversy is between the proponents of Insulated Ceramic heater bands and Mica heater bands. It also concerns the effects of shrouding on heater band efficiency.

We saw in the energy chart presented previously that heating accounts for 14% of required energy, so it is a subject that should be investigated. In order to read more about this discussion, you may refer to APPENDIX G.3.

7.8 INJECTION MACHINE HEATERLESS NOZZLES

There is available on the market a new concept in nozzles for injection molding machines. It does not require any heating bands but is gas filled and obtains its heat from the barrel and from frictional heat of the material.

It is an energy saver but also saves down time from broken heater band wires and drool problems effecting the nozzle heater bands.

Further details can be found in APPENDIX G.4.

8. ENERGY SAVINGS IN EXTRUSION

Next in volume of energy consumption to the injection molders, come the extruders, if all types of extrusion are grouped together, including wire and cable coating. However, the scope of energy conservation in the operation of the equipment is not as broad. There are not as many actions and functions on an extruder to create energy inefficiency. Estimates of the efficiency of an extruder operation run as high as 40 to 60%. This means there is not the fertile field for energy conservation that there was in injection molding; but there is still enough potential to make a conservation program worthwhile.

Although natural gas is used in at least one of the extruder based processes, it is mainly used by most firms for building heat. Having dealt with general plant energy saving methods in the earlier section, we will concentrate on electric energy connected with extruder operation.

8.1 DRIVE EFFICIENCY OF EXTRUDERS

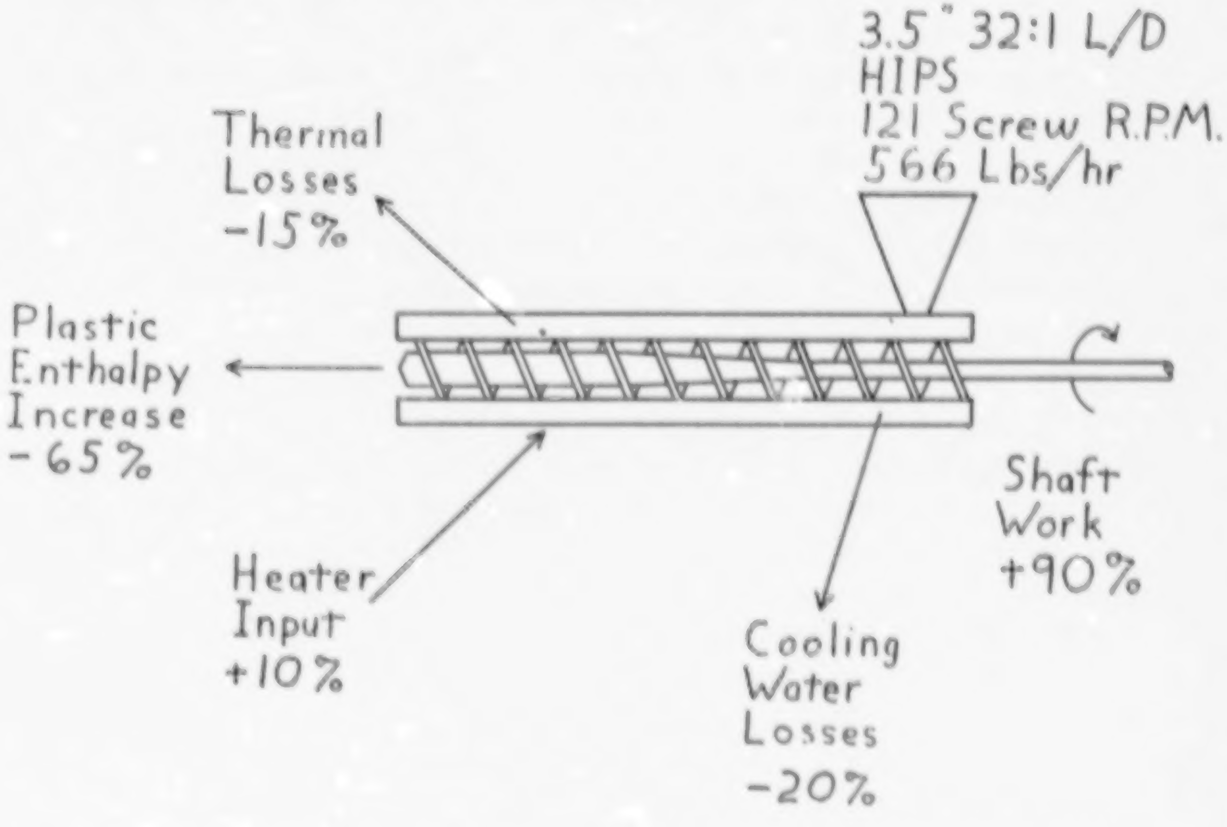
Most extrusion machine manufacturers seem to agree that solid state, D.C. direct drive with helical gearing produces the most energy efficient results. This is particularily true if they can be operated at the proper base speed for the particular motor. The penalty in energy inefficiency, if operated lower than 50% can be severe.

The A.C. type motor is efficient and may come into more common use if costs can be reduced on speed controls. There are also claims being made about the energy efficiency of hydraulic type drives with variable displacement pumps. Clutch drives are considered to produce high energy losses.

Articles in APPENDIX H.1. go into this subject in technical detail.

8.2 ENERGY REQUIREMENTS AND LOSSES ON EXTRUDERS

The schematic diagram below shows the relative energy loss areas on an extrusion machine in connection with the barrel and screw.(*)


3.5" 32:1 L/D
HIPS
121 Screw R.P.M.
566 Lbs/hr
Thermal Losses -15%
Plastic Enthalpy Increase -65%
Heater Input +10%
Cooling Water Losses -20%
Shaft Work +90%

(*) NRM Corporation, Akron, OHIO

Naturally, control of stock temperature is the key to energy efficient operation and the closer the running condition is to adiabatic the more energy will be saved. This comes from the fact that the closer the melt conditions are to correct, at the time of delivering the resin to the die, the less energy needs to be supplied; for cooling if the stock is too hot, or conversely, for heating if the stock is too cold.

This is a procedural control situation but it also goes back to having the right machine specifications for the job. The machinery manufacturers are finding that more extrusion firms are realizing the cost penalty in productivity, of not tailoring the machine to material and job they are running. This is all important at the time of purchasing a new machine, and should be easy enough for those firms operating dedicated lines. It becomes for more difficult for the custom extruder who is running numerous jobs and using various resins.

If it is possible to order a machine with tight specifications in regard to its proposed work, it is suggested that it be designed to operate at 80 - 100% adiabatic conditions. Keep in mind it also costs energy to cool if the extruder operates at higher than 100% adiabatic conditions.

This is why every extruding firm must investigate their own best energy saving approach, depending on their product and material, when it comes to insulation blankets on the barrel. There are a number of different types, such as stainless steel wire knit, mineral fibre knit and fibreglass fabric. If any of these are used, there must still be circulation of air under the blanket. Total energy consumption must be calculated including drive, heating and cooling to arrive at the most economical approach for each situation.

There are both air cooled and water cooled extruders.

Regardless of which type is preferred, there are energy saving techniques to recapture otherwise lost heat. If the aircooled system is being used, some of the heat is being utilized to heat the work area. However, much of it is wasted. A good approach is to duct some of this to the hopper and predry the resin. Some materials require more drying than others but in humid conditions, it will help extrusion conditions and save energy at the same time. Preheating may reduce torque needed for the extruder.

On the other hand, if the extruder is water cooled, the water can be cascaded for reuse downstream - feed throat -gear reducer oil cooling - feed screw.

A waste of energy can occur when screen packs are not changed regularily. A clogged screen pack will cause a build up of pressure which in turn consumes more energy. The use of automatic screen changers will pay off quickly.

8.3 SCREW DESIGN FOR EXTRUSION MACHINES

There are no arguments that screw design is the single most important feature on an extrusion machine when it comes to productivity and thus energy conservation. However, there are many screw designs available and not everyone is in agreement as to the best. Again it is a matter of design in relation to the exact job it is expected to do. Here, once more, an extrusion firm running a dedicated line should work closely with the machinery manufacturer, and not only match the screw to the job and material, but the whole machine should be compatible for optimizing the results.

For the custom extruder it is far more difficult. However, the machine and screw should be ordered to match the need of the majority of work expected and not try to be 100% universal.

The custom extruder should also be prepared to have a variety of screws and change them for the best results for a reasonable run. The machinery manufacturers feel the extruders underestimate the penalty they are paying for using a poorly designed screw for the job they are doing.

The basic purpose of any screw is to deliver the stock to the die, in a suitable melt condition at the highest rate of productivity, at the lowest cost. This is where the refined technology of screw design is really paying off. An extruder should work very closely with the extruder manufacturer, to take advantage of the precise design features which will produce the best results.

We will not try to discuss design in further detail in this part of the report, but please refer to APPENDIX H.1. for articles on technical aspects of this most important subject

8.4 SCREW MAINTENANCE IN EXTRUSION MACHINES

Many processors underestimate the penalty of lower productivity and higher energy costs, caused by screw and barrel wear. The tendancy is to use more horse power and adjust conditions to compensate for the condition. This, not only is more costly from the energy standpoint but it can cause unstable extrusion conditions which in turn can lower productivity and quality.

Periodic checking of the screw and barrel condition, depending on the type of resin being used, will alert the processor to possible trouble. Repair or replacement will pay-back the cost suprisingly quickly.

An excellent article on this subject is contained in APPENDIX H.1.

8.5 SPECIAL ENERGY SITUATIONS RELATED TO EXTRUSION

One of the large energy conservation changes reported was in wire and cable coating, downstream from the extrusion machines. This was the use of nitrogen for curing XLPE (cross link polyethylene) instead of the former use of high pressure steam.

This was basically instigated to improve product quality but the energy saving was an added bonus.

Another area of potential saving is in the film blowing process. This is most difficult, but obviously someone will come up with some solutions.

Recapturing the heated air from the film tower has good potential. However, the difficulty lies in trying to remove the heat without distrubing the film bubble.

There is also possibilities in die insulation and die cooling in the film blowing process.

9. ENERGY SAVINGS IN OTHER PROCESSES

We have spent considerable time discussing the Injection and Extrusion related processes. We felt this to be appropriate because these two processes use 75% of the total energy in the Plastics Processing Industry. They also offered the greatest potential in conservation.

However, we found some interesting areas of investigation in other processes and we will cover the highlights. Many of the areas of possible energy saving in Injection and Extrusion will apply to other processes where there is hydraulic action and screw feed.

One of the things common to some of the following processes is the difficulty in recapturing plant heat because of various types of fumes involved. This also applied to some of the particular types of Injection and Extrusion plants on certain resin applications.

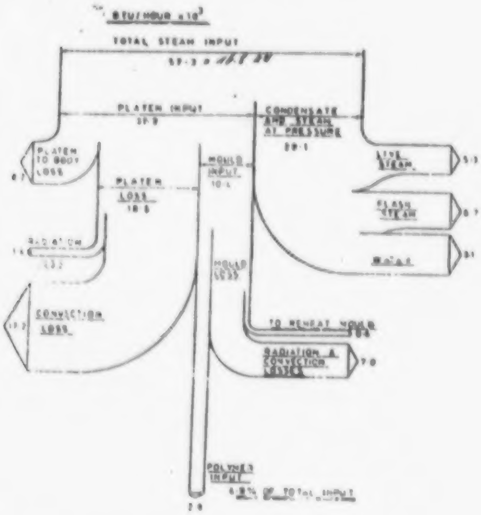
Simple air transfer methods cannot be employed in these cases. A more expensive heat exchanger must be used and this means longer pay-back. However, each situation should be costed, as with rising energy costs the system may become cost effective.

9.1 COMPRESSION AND TRANSFER MOLDING

The items covered in Injection molding in regard to hydraulics, certainly apply equally to Compression molding. The longer cycles make the pressure control even more important.

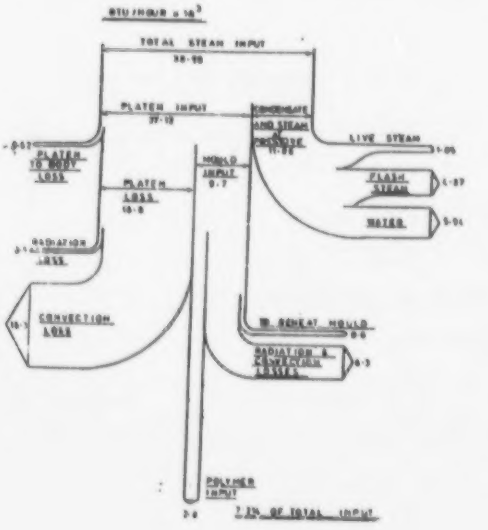
ENERGY INPUT TO and LOSSES FROM
A COMPRESSION MOULDING PRESS. (BEFORE MODIFICATION)
PLATEN TEMPERATURE 180 °C

(*)


BTU/HOUR x 10³
TOTAL STEAM INPUT
57.3
PLATEN INPUT
37.9
CONDENSATE AND STEAM AT PRESSURE
29.1
PLATEN TO BODY LOSS
0.7
LIVE STEAM
5.3
MOULD INPUT
10.4
PLATEN LOSS
18.5
FLASH STEAM
8.7
RADIATION LOSS
1.6
WATER
8.1
MOULD LOSS
CONVECTION LOSS
17.2
TO REHEAT MOULD
RADIATION & CONVECTION LOSSES
7.0
POLYMER INPUT
2.8
4.9% OF TOTAL INPUT

(*)

ENERGY INPUT TO and LOSSES FROM
A COMPRESSION MOULDING PRESS. (AFTER FURTHER PLATEN INSULATION MODIFICATION)
PLATEN TEMPERATURE 180 °C


BTU/HOUR x 10³
TOTAL STEAM INPUT
38.99
PLATEN INPUT
27.12
CONDENSATE AND STEAM AT PRESSURE
11.86
0.57
PLATEN TO BODY LOSS
LIVE STEAM
1.05
MOULD INPUT
9.7
PLATEN LOSS
18.0
FLASH STEAM
4.87
WATER
5.94
RADIATION LOSS
CONVECTION LOSS
15.1
TO REHEAT MOULD
0.6
RADIATION & CONVECTION LOSSES
6.3
POLYMER INPUT
2.8
7.2% OF TOTAL INPUT

(*) Institute of Plastic Processing
Institut fur Kunststoffverarbeitung (IKV)
Aachen, Federal Republic of Germany

Because of the higher heats on the mold itself, the mold should be insulated from the platen to reduce heat lost to the body of the machine. The mold can also be insulated although this is more difficult without causing interference with the operation. It can pay off however, as illustrated in the following charts, showing energy loss before and after insulation modifications.[23]

9.2 BLOW MOLDING

This process also uses hydraulics and a screw feed so again many of the subjects discussed in the Injection and Extrusion sections will apply.

Unlike those processes however, the blow molding firms use considerable natural gas for post molding operations in flaming the product. This is preparing the surface for a secondary operation of printing.

A process replacing this flaming operation has been developed and is in operation in some plants in the U.S.A. It is a method of electro treating the plastic surface. The initial capital expenditure is quite large and therefore the question of pay-back must be determined.

However, even with the flame treating method, there may be ways of reducing energy loss and it is an area that might be productive for an energy conservation committee.

9.3 ROTATIONAL MOLDING

This process uses considerable natural gas in both the oven type of production and even more in the open flame equipment. The best chance of conservation here is to encapsulate the open flame and reduce the loss of heat to the atmosphere.

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[23] Institute of Plastic Processing
Institut fur Kunststoffverarbeitung (IKV)
Aechen, Federal Republic of Germany

There is always the argument in processes with loss of heat to the atmosphere that it is helping to heat the plant. This is definitely true but in most cases you will find it is more than necessary and much heat is still wasted.

9.4 EXPANDED BEAD PROCESSES

Steam is the major energy use in these plants. Naturally in the steam plant itself, the condensate should be returned to the boiler for feed water.

However, the biggest loss is the steam released to the atmosphere in the process itself. This applies equally to form and shape molding as well as to block and sheet molding. The steam cannot be restricted during the bead expansion cycle. Here again is an area of potential saving if someone can devise some means of utilizing this energy loss to atmosphere.

9.5 REINFORCED PLASTICS

In most areas of reinforced plastics, the general plant suggestions will prove most effective. Of course, for those firms who mold with hydraulic procedures, many of the Injection or Compression energy saving techniques will apply.

However, the recovery of plant air is a major source of conservation. Because of the quality of air required, it will mean heat exchangers at higher capital cost and reasonable pay-back will have to be considered.

9.6 STRUCTURAL FOAM

All of the general plant procedures will apply here as well as then specific areas of energy savings discussed in Injection molding.

10. MICROPROCESSOR CONTROLS

We have left this subject until now because it effects the whole industry and its future in remaining competitive in the world market. Productivity and energy conservation become one and the same thing at this stage.

If processors are going to fine tune thier operation, they will have to use every bit of new technology available. This applies equally to blow molders, extruders, injection molders and all other machinery oriented segments of the industry.

Just moving to solid state controls was a major step in the maintenance problems. Now there is a bigger step into microprocessor controls and this frightens the processors even more. Not only the cost is a problem but here again, the training their employees will need, is holding them back.

However, the fact remains that most people in the control business, consider the experimental stage as passed. There will be future improvements but no processor needs to feel they are being used as guinea pigs.

The processors who have ventured into these areas of microprocessor controlled equipment, are reporting much faster pay-back than they anticipated. They are upgrading their personnel to fully utilize the resources available to them and this is one of the main keys to success.

The emphasis on this subject throughout this entire study was a dominate feature. This came from processors in Canada and Germany. It also came from basic machinery manufacturers in all countries where calls were made. The message was strong and clear that precision molding was no longer just a need for close tolerance parts, but was equally important for all processing in order to improve productivity and quality. This would then make a direct contribution to energy conservation.

The basic advantage of the microprocessors is their ability to preprogram set-ups for faster starts. They then can control the variables inherent in processing such as materials, molds and power. However, one of the largest advantages reported by most users is that it stops fiddling with the controls by each new successive shift as personnel come on duty. One processor estimates this alone gave the expenditure a fast pay-back.

In Canada, a lack of personnel trained on new technology is a definite handicap. The comparison with operations in Germany emphasized this point. They are at the stage where this type of equipment is commonplace and they would consider it part of the basic machine and not an option.

For more detailed reading on this important subject, please refer to APPENDIX I.1.

11. ENERGY SAVING IN AUXILIARY EQUIPMENT

Processors are liable to overlook the large consumption of energy by auxiliary equipment such as grinders, dryers and conveyor belts. This is especially true if they are idling, when they become inefficient in their energy draw. As some of this auxiliary equipment is common to many of the processes, we have kept this in a separate section.

It has been common practice to leave a grinder running beside an injection machine to accommodate the spasmodic need for grinding runners, sprues and rejects. A timed test in one plant revealed the grinder was only actually grinding two hours out of 24. The balance of the time it was just idling. Voluntary shut down by the operator does not work satisfactorily so this firm equipped every grinder with automatic shut-offs after the grinder went off load. Pay-back was less than one year.

Some of the new grinding procedures developed by the machinery manufacturers is far more energy efficient than the older styles.

Another area of waste is the design feature of the older desiccant dryers. These ran continually, changing from one bed to the other, regardless of the through-put of the material. Here again, the newer machines are more energy efficient. However, older models can be equipped with dew point sensors and shut down at a given set-point for the particular job and material. One molder found after such a retrofit, the dryer only needed to operate 20% of the time to satisfy the requirements.

There are usually numerous pieces of machinery in any plant that are left running when not being used. A constant plant audit by the energy conservation committee can reduce the incidence of this until everybody is really energy conscious.

Some examples of the newer energy efficient equipment is shown in APPENDIX J.1.

12. ENERGY MONITORING EQUIPMENT

One of the frustrating aspects of energy conservation for anyone working in this area has been the absence of suitable monitoring equipment. The machinery manufacturers use very sophisticated devices and usually express energy efficiency in percentages or as a comparison to other machines.

What is needed in a processing plant is an instrument at a reasonable price, which is portable, and which expresses energy consumption in absolute terms. Some of these are now available and any plant would be well advised to use one as part of their program. The pay-back will be very fast, as for the first time processors will be able to see on a digital read-out the actual energy being consumed as each function is performed and also the cumulative totals. Technicians will be able to see directly and immediately the most energy efficient set-up and control procedures.

This equipment is clip-on and therefore, can be moved from machine to machine easily. One model is more expensive than the other because it is equipped with a print-out as well as the digital read-out.

Two of the instruments available are illustrated in APPENDIX K.1.

13. RECOMMENDATIONS AND CONCLUSION

We have seen by the energy conservation potential analysis that procedural activities account for about 3/4 of the total of 25.2% of the possible savings by 1984. This can be accomplished with activities that involve no capital expenses or capital expenditure with pay-back of less than two years.

In the survey, we found the dominant reluctance of processors to start a program was their perception that it would involve a lot of money and time. From the firms operating highly successful energy conservation programs, we found this not to be the case. We also discovered that without exception, those firms who had seriously developed a program were astounded at what they had accomplished and the amount of money they had saved.

Therefore, our recommendations are very simple. Keeping in mind the small size of the majority of the processors, we would recommend a very basic approach, but the main thing is to get started.

Initial action steps could be as follows:

- organize a committee.
- publicize the activity throughout the firm.
- start on procedural high profile items.
- obtain some outside assistance to guide the committee
- decide on a production unit for energy cost comparison.
- monitor the results on a regular basis (weekly preferred).
- get as many employees involved as possible.
- continue to publicize results to keep up interest.
- brainstorm for ideas.
- provide the committee with literature of other successful program case histories.
- make sure top and middle management are heavily involved.

- keep it simple - time and cost effective.
- stick with it - as it will probably take the first year before energy conservation becomes a way of life throughout the organization.

The amount of actual literature supplied in the appendices is presented in the hope it will be direct assistance to any energy conservation program in the Plastic Processing Industry. Many of the articles would not be readily available and the others we believe are more helpful, if they are presented in one easily accessible volume.

The particular equipment included in the appendices does not imply any endorsement. There are many other manufacturers and their products should be investigated also. However, we have included some items to illustrate energy conservation possibilities and to spark ideas, knowing some of the equipment that is becoming available.

We conclude this study by thanking once again all those people who gave generously of their valuable time to make this report possible.

APPENDIX A

PLASTIC PROCESSORS INTERVIEWED

APPENDIX A

CANADIAN PROCESSORS INTERVIEWED

FIRM & ADDRESS	CONTACT	PROCESS TYPE
ABC PLASTIC MOLDING 20 Brydon Drive Rexdale Ontario M9W 5R6 416-743-6731	Mr. R. Talbot Plant Manager	Industrial Blow
ACKRIPAK 8100 Keele St. Maple Ontario L0J 1E0 416-669-1331	Mr. N.P. Simpson General Manager	Injection
ACTIPLAST INDUSTRIES LTD., 3303 57 Ave.,SE Calgary Alberta T6C 0B2 403-265-2381	Mr. R.M. Pogue President	Reinforced
BEDFORD INDUSTRIES LTD., 4750 Blvd. des Grandes Prairies Montreal Quebec H1R 1A3 514-325-4410	Mr. S.G. Halifax Vice-President Operations	Injection
BIG "O" DRAIN TILE CO., LTD., P.O. Box 189 Hensall Ontario N0M 1X0 519-262-2924	Mr. B. Menary Plant Manager	Extrusion Drain Pipe
BONAR ROSEDALE PLASTICS LTD., P.O. Box 88 111 Verulam Road Lindsay Ontario J9V 4R8 705-324-6701	Mr. H. Reese Vice-President & General Manager	Rotational
BOW PLASTICS LTD., 5700 Cote de Liesse Montreal Quebec H4T 1B1 514-735-5551	Mr. S. Bern President	Injection Extrusion Blow

CANADIAN PROCESSORS INTERVIEWED (continued)

BROMAR PLASTICS LTD., 10551 Ray Lawson Blvd., Ville D'Anjou Quebec H1J 1M3 514-351-7560	Mr. S. Keats President	Blow Bottle
CAMPBELL FILMS LTD., 225 Hughes Road Orillia Ontario L3V 6K8 705-325-2358	Mr. W.A.Swinimer General Manager	Extrusion Film
CANADA CUP LTD., 137 Bentworth Ave., Toronto Ontario M6A 1P6 416-789-5151	Mr. J. West Plant Manager	Injection Thermoform Expanded Bead
CANADA PLASTIC CONTAINERS LTD., 1200 Ellesmere Road Scarborough Ontario M1P 2X4 416-293-8233	Mr.E.Zimmerman President	Injection Injection Blow
CANADA WIRE AND CABLE 22 Commercial Road Toronto Ontario M4G 1Z4 416-421-0440	Mr. R. Yoeman Manager Manufacturing Engineering	Extrusion Wire Coating
CANADIAN GENERAL ELECTRIC 755 Division St., N. Cobourg Ontario K9A 3T1 416-372-5411	Mr. R. Zarboni Manager-Resins and Molded Plastics	Injection Compression Filament Injection Thermoset
CANADIAN GENERAL TOWER 52 Middleton St., Cambridge Ontario N1R 5T6 519-623-1630	Mr. J.C. Phillips Operations Manager	Calendering

CANADIAN PROCESSORS INTERVIEWED (continued)

CANADIAN KEYES FIBRE CO., LTD., 30 Iron St., Rexdale Ontario M9W 5E1 416-249-2221	Mr. R. D. Crooks Operation Manager	Foam Food Trays
CANADIAN PLASTIC PAK LTD., 668 Derwent Way New Westminister British Columbia V3M 5P8 604-522-1601	Mr. B. Gallop President	Blow Bottle
CANPLAS INDUSTRIES LTD., 286 Bayview Drive P.O. Box 667 Barrie Ontario L4M 4Y5 705-726-3361	Mr. A. Kinsella Manufacturing Manager	Injection
CANPLAST OF CANADA LTD., 4707 Blvd. Couture St. Leonard Quebec H1R 3H7 514-322-5112	Mr. M. Dallaire Plant Engineer	Extrusion Laminates
CAPILANO PLASTICS LTD., 1081 Cliveden Ave., New Westminister British Columbia V3M 5V1 604-526-9711	Mr. S. Thompson Plant Manager	Injection
GEO. CLUTHE MFG. CO., LTD., 586 Kumpf Drive Waterloo Ontario N2J 2Z7 519-885-4540	Mr. H.J. Braun Maintenance Manager	Injection
COLUMBIA PLASTICS LTD., 2155 W. 10th Ave., Vancouver British Columbia V6K 2H7 604-736-9261	Mr. G.Howard General Manager	Injection Compression

CANADIAN PROCESSORS INTERVIEWED (continued)

DAYMOND DIVISION OF REDPATH INDUSTRIES 2441 Royal Windsor Drive Mississauga Ontario L5J 4C7 416-823-4423	Mr. H.J. Skinner Manager Codes & Standards	Extrusion Siding
DONLEE PLASTICS 1935 Wilson Ave., Weston Ontario M9M 1A9 416-741-9210	Mr. P. Murray General Manager	Blow Industrial
Engineered Profiles Ltd., 7024 30th St., SE Calgary Alberta T2C 1N9 403-279-4497	Mr. W. Hutchings President	Extrusion
ENVIROGLAS 219 Jamieson Bone Rd., P.O. Box 1088 Belleville Ontario K8N 5E8 613-966-7660	Mr. H.E. Stark Vice-President Manufacturing	Filament Winding
FLEX-PAK LTD., 13320 River Road Richmond British Columbia V6V 1W7 604-273-9277	Mr. W.M. Shaw General Manager	Extrusion Film
GENERAL MOTORS OF CANADA Division St., Oshawa Ontario L1G 1K7 416-644-6006	Mr. R. Watson Plastic Fabrication Manufacturing Engineering	Injection RIM (captive)
G.M.PLASTICS EXTRUSION DIV.OF G.M.PLASTICS GROUP LTD., 3655 Blvd. Losch St. Hubert Quebec J3Y 5T7 514-656-2020	Mr. M.Djoukhadjian Vice-President Manufacturing	Extrusion Sheet Profile

CANADIAN PROCESSORS INTERVIEWED (continued)

GRANDVIEW INDUSTRIES 110 Ronson Drive Rexdale Ontario M9W 1C2 416-245-2244	Mr.H. Schoettler Manager Manufacturing	Extrusion Pipe
HIGHLAND MFG. CO., LTD., 7326 Antrim Avenue Burnaby British Columbia V5J 4M8 604-437-5505	Mr. S. Green President	Injection Compression
HORIZON PLASTICS LTD., P.O. Box 474 Cobourg Ontario K9A 4L1 416-372-2291	Mr. C. Elliott President	Structural Foam
INTERVERSAL INDUSTRIES LTD., 1351 Hastings Cres., SE Calgary Alberta T2G 4C8 403-243-1263	Mr. R. Thicket Ass't General Manager	Injection
KORLIN 577 Erie Street Stratford Ontario N5A 6V6 519-271-1680	Mr. J. Weir Vice-President & General Manager	Extrusion Sheet
LECO INDUSTRIES LTD., 36 Tidemore Ave., Rexdale Ontario M9W 5H4 416-742-3060	Mr. W. Baker Vice-President Research and Corp. Dev.	Extrusion Film
LISTO PRODUCTS LTD., 1445 Charles St., Vancouver British Columbia V5L 2S7 604-253-8488	Mr. W. Sinitsin President	Injection

CANADIAN PROCESSORS INTERVIEWED (continued)

MAPLE LEAF PLASTICS 375 Danforth Road Scarborough Ontario M1L 3X9 416-698-2545	Mr. P. Rothstein President	Compression Injection
MIDLAND INDUSTRIES 320 Elizabeth St., Midland Ontario L4R 4L6 705-526-7801	Mr. A. Mudde Plant Manager	Injection Compression
MITCHELL PLASTICS LTD., 11 Hoffman St., Kitchener Ontario N2M 3M5 519-744-4197	Mr. M.J. Ariss President	Injection
MODERN PLASTICS LTD., 6525 Picard St., St. Hyacinthe Quebec J2S 1H3 514-774-5017	Mr. A. Pelletier General Manager	Injection Blow
MOLDCRAFT PLASTICS LTD., 362 Silvercreek Pkwy. Guelph Ontario N1H 6N3 519-821-2340	Mr. F. Zotter President	Compression
MOLDEX LTD., 316 Bayview Drive Barrie Ontario L4N 4Y8 705-726-0283	Mr. W. C. Davison Director Manufacturing & Engineering	Injection Compression
MORVAL DURAFOAM LTD., P.O. Box 878 152 Birch Avenue Kitchener Ontario N2G 4E1 519-579-6100	Mr. R. Knox Plant Engineer	Expanded Bead: Sheet Molded Shapes Extrusion: Sheet Profile

CANADIAN PROCESSORS INTERVIEWED (continued)

MULTI FITTINGS DIVISION OF REDPATH IND.,LTD., 1055 Wilton Grove Road London Ontario N6A 4K3 519-681-2140	Mr. L. Pickering Plant Manager	Injection
NORTH AMERICAN PLASTICS LTD., Base Line Road Wallaceburg Ontario N8A 4L5 519-627-6061	Mr. R. Fisher Plant Engineer	Injection
PHILLIPS CABLES LTD., King Street Brockville Ontario J7Z 5V9 613-345-5666	Mr. G. Bamber Plant Manager	Extrusion Wire & Cable Coating
PHILLIPS EXTRUDED PRODUCTS LTD., 7083F 35th St.,SE Calgary Alberta T2C 1V3 403-279-7471	Mr. W.C. Nicol Sales Manager	Extrusion Pipe
PLASTALENE CORP.,LTD., 675 Simonds South Granby Quebec J2J 1C2 514-378-4625	Mr. J.C. Bonnett Vice-President Marketing	Extrusion Sheet Profile
PLASTI-FAB INDUSTRIES LTD., 8115 Rue Lafrenaie St. Leonard Quebec H1P 2B1 514-325-9840	Mr. E. Waldhart President	Extrusion Profile Rod
PLASTI-FAB LTD., 625 28th St., NE Calgary Alberta T2A 4L6 403-273-0996	Mr. B. Burgess General Manager	Expanded Bead Sheet Block

CANADIAN PROCESSORS INTERVIEWED (continued)

PLASTOMER LTD., 151 John Street Barrie Ontario L4N 2L1 705-726-0225	Mr. R. Tripp Plant Manager	Injection Compression
PLAX DIVISION OF BRADLEY-FENN ENTERPRISES LTD., 4041 North Service Road Burlington Ontario L7L 4X6 416-827-7616	Mr. G.D. Bradley Vice-President	Blow Bottles
POLY-CHLOR PLASTIC IND.,LTD., 45 Leeder Street Coquitlam British Columbia V3K 3V5 604-524-9585	Mr. H. Peters Plant Manager	Extrusion Profile
PRECIFORM INC., 3035 Blvd.le Corbusier Laval Quebec H7L 4C3 514-687-5115	Mr. A. Piedalue Director of Operations	Extrusion Profile
PROGRESSIVE MOULDED PRODUCTS 111 Martin Ross Ave., Downsview Ontario M3J 2M1 416-661-9800	Mr. T. Nichols Plant Manager	Injection
PROTECTIVE PLASTICS P.O. Box 156 50 Passmore Avenue Milliken Ontario L0H 1K0 416-291-9581	Mr. L. Benko Director of Manufacturing	Reinforced Compression Filament
RAY PLASTICS LTD., 91 Westmore Drive Rexdale Ontario M9V 3Y6 416-749-2511	Mr. R. Fournier President	Injection

CANADIAN PROCESSORS INTERVIEWED (continued)

REHAU INDUSTRIES INC. P.O. Box 1240 Churchill Road Prescott Ontario K0E 1T0 613-925-4281	Mr. O. Braganza Plant Manager	Extrusion Pipe
RUBBERMAID(CANADA) LTD., 2562 Stanfield Road Mississauga Ontario L4Y 1S5 416-279-1010	Mr. W. Wood Engineer	Injection Rotational
SAUDER INDUSTRIES LTD., 13,880 Viking Place Richmond British Columbia V6V 1K8 604-273-8734	Mr. R. Darke General Manager	Extrusion Siding Lamination
SCEPTER MFG.,CO.,LTD., 11 Bermondsey Road Toronto Ontario M4B 1Z3 416-751-3820	Mr. T. Torokvei President	Injection Extrusion Blow
SOMMERVILLE PLASTICS 376 Orenda Road Bramalea Ontario L6T 1G1 416-791-4440	Mr. M. Geofreda General Manager	Injection
STAX PLASTICS LTD., 95 The East Mall Toronto Ontario M8Z 5X9 416-236-2371	Mr. G. McLung General Manager	Expanded Bead: Cups
TARXIEN CO.,LTD., 505 Finley Ave., Ajax Ontario L1S 2E2 416-683-1681	Mr. I. Medad General Manager	Injection

CANADIAN PROCESSORS INTERVIEWED (continued

TORONTO PLASTICS LTD., 2045 Midland Avenue Scarborough Ontario M1P 3E2 416-293-1156	Mr. J. Dimitru Controller	Injection Extrusion
TWINPAK INC., 2225 Hymus Blvd. Dorval Quebec H9P 1J8 514-684-7070	Mr. G. Ringrose Director of Corp. Engineering	Injection Extrusion Blow
VITAFOAM PRODUCTS CANADA LTD., 150 Toro Road Downsview Ontario M3J 2A9 416-630-6633	Mr. G. Gurley Plant Manager	Foam
WEDCO INDUSTRIES LTD., 1289 Newton St., Boucherville Quebec J4B 5H2 514-655-7220	Mr. D. Guibault President	Blow Rotational
WESTERN CONCORD MFG.,LTD., 880 Clivedon St., New Westminister British Columbia V3M 5R5 604-525-5331	Mr. W. Zahirney Plant Manager	Extrusion Rotational
WESTROC INDUSTRIES LTD., 2457 Lakeshore Hwy. Mississauga Ontario L5J 1K4 416-823-9881	Mr. W.R. Macondald General Manager	Extrusion Siding
WOODBRIDGE FOAM CORP., 200 Ronson Drive Rexdale Ontario M9W 1P7 416-243-3445	Mr. E. Gatta Vice-President Planning & Development	Foam

APPENDIX B

PLASTIC MACHINERY MANUFACTURERS AND CONTROL MANUFACTURERS.

The following list includes only those firms who assisted this survey by supplying energy related information.

APPENDIX B

PLASTIC PROCESSING MACHINERY MANUFACTURERS AND AGENTS

The following list includes only those firms who were interviewed personally or who supplied information for this study. It includes basic processing equipment and also auxiliary and control equipment.

It should be clearly understood that this list does NOT include all equipment available nor does it imply any sort of recommendation. It is presented solely to recognize the assistance given by these firms in this project.

For a more complete list of equipment sources, please consult:
CANADIAN PACKAGING BUYERS' GUIDE(MACLEAN-HUNTER)
CANADIAN PLASTICS DIRECTORY & BUYERS' GUIDE (SOUTHAM PRESS)
ENERGY MANAGEMENT CANADA (LAKEVIEW PUBLICATIONS)
MODERN POWER AND ENGINEERING -ENERGY CONSERVATION SOURCE BOOK(MACLEAN-HUNTER)
MODERN PLASTICS ENCYCLOPEDIA (McGRAW HILL)
PLASTICS BUSINESS (KERRWIL)
PLASTICS MACHINERY AND EQUIPMENT (INDUSTRY MEDIA)

ALLEN-BRADLEY CANADA LTD., 135 Dundas St., Cambridge Ontario N1R 5X1 519-623-1810	Mr. W. C. Torrance Vice-President	Load Management Controls
APPLICATION ENGINEERING CORP., 850 Pratt Elk Grove Village Illinois 60007 312-593-5000	Mr. M.A. Waters	Heat Exchangers Temperature Controllers
BARBER-COLMAN OF CANADA LTD., 1875 Wilson Ave., Weston Ontario M9M 1A4 416-742-6210	Mr. P.M. Fenrich Manager	Process Controllers Temperature Controllers

PLASTIC PROCESSING MACHINERY
MANUFACTURERS AND AGENTS (continued)

BATTENFELD MASCHINENFABRIKEN GMBH. D-5882 Meinerzhagen Federal Republic of Germany	Dipl.-Ing. H.Eckardt	Injection Blow RIM Extrusion Thermoform
BEKUM PLASTICS MACHINERY LTD., 309 Evans Ave., Toronto Ontario M8Z 1K2 416-255-7736	Mr. S.H. Raumann General Manager	Blow Extrusion Injection Blow
P.R. BOON SALES INC., (AGENT) General Delivery Whistler British Columbia VoN 1B0 604-932-4536	Mr. P.R. Boon President	Injection Extrusion Blow Auxiliary
BRAMPTON ENGINEERING INC., 8031 Dixie Road S Brampton Ontario L6T 3V1 416-493-3000	Mr. P. Gates	Extrusion
CINCINNATI MILACRON CO., 4165 Halfacre Rd. Batavia Ohio 45103 516-536-2000	Mr. M.B. Klaus Director Product Management	Injection Extrusion Blow
CONNAIR CANADA LTD., 5535 Timberlea Blvd. Mississauga Ontario L4W 2S4 416-625-2965	Mr. A.C. Hamilton President	Dryers Granulators Loaders
DAVIS CONTROLS LTD., P.O. Box 160, 4251 Dundas St.W Toronto Ontario M9A 4X2 416-233-3211	Mr. J. Wiggins	Load Management Controllers

PLASTICS PROCESSING MACHINERY MANUFACTURERS AND AGENTS (continued)

DAVIS STANDARD DIV., COMPTON & KNOWLES CORP., U.S. Route 1 Pawcatuck Connecticut 02891 203-599-1010	Mr. A.A. Arterton Manager Research & Development	Extrusion
LUDWIG ENGEL CANADA LTD., 545 Elmira Road Guelph Ontario N1K 1C2 519-836-0220	Mr. P. Anbeek	Injection
EN-PLAS INC. (AGENT) 40 Continental Pl. Scarborough Ontario M1R 2T4 416-292-7400	Mr. A. Lemieux President	Injection Blow Extrusion Auxiliary
FARREL CONNECTICUT DIV. EMHART MACHINERY GROUP Ansonia Connecticut 06401 203-734-3331	Mr.J.P. Bohenko Research Engineer	Injection Extrusion Compounding
FLAG MACHINERY LTD., 270 Esna Park Road Markham Ontario L3R 1H3 416-475-6116	Mr. V.C. Waller Managing Director	Extrusion Injection Blow Auxiliary
HPM CORPORATION 820 Marion Road Mount Gilead Ohio 43338 419-946-0222	Dr.R.E.Nunn Director Research & Development	Injection Extrusion Vacuum Form

PLASTICS PROCESSING MACHINERY

MANUFACTURERS AND AGENTS (continued)

ERIC HAGEN & CO.,LTD., (AGENT) 3495 Hawkestone Road Mississauga Ontario L5C 2V1 416-273-5200	Mr. E. Hagen President	Injection Blow Compression Auxiliary
A.C. HAMILTON & CO., (AGENT) 5585 Timberlea Blvd. Mississauga Ontario L4W 2S4 416-625-2965	Mr. A.C. Hamilton President	Injection Blow Compression Auxiliary
HONEYWELL LTD., 740 Ellesmere Road Scarborough Ontario M1P 2V9 416-491-1300	Mr.J. Bloie Sales Engineer	Load Management Controllers
HUSKY INJECTION MOLDING SYSTEMS LTD., P.O. Box 1000 Bolton Ontario L0P 1A0 416-857-3240	Mr. D. Cook Vice-President Marketing	Injection Injection Blow
KAWAGUCHI LTD., 988 Sodeshi-Cho Shimizu Shizuoka Japan		Injection
KONA CORPORATION P.O. Box 1227 Blackburn Drive Gloucester Massachusetts 01930 617-281-3810		Injection Nozzles
NETSAL-MASCHINEN AG CH-8752 Nafels Switzerland	Dr. T. Coppetti Technical Director	Injection

PLASTICS PROCESSING MACHINERY

MANUFACTURERS AND AGENTS (continued)

KRAUSS-MAFFEI CORP., P.O. Box 9104 3629 W. 30th St. S Wichita Kansas 67277		Extrusion RIM
MOULDERS SUPPLY LTD. (AGENTS) 192 Oakdale Road Downsview Ontario M3N 2S5 416-745-3897	Mr. F. Reid Vice-President	Injection Extrusion Blow RIM Auxiliary
MOULD-TEK IND.,INC., (AGENTS) 733 Progress Avenue Scarborough Ontario M1H 2W7 416-438-6875	Mr. K. Hoffman General Manager	Injection Thermoform Auxiliary
NRM CORPORATION A CONDEC COMPANY 180 South Ave. Tallmadge Ohio 44278 216-633-1600	Mr. T. Becker Director Product Engineering	Extrusion Blow
NISSEI PLASTIC IND.,CO.,LTD., Sakakimachi Nagano-Ken Japan		Injection Injection Blow
PACKAGE MACHINERY CO., REED-PRENTICE DIV., East Longmeadow Massachusetts 01028 413-525-6441	Mr. B.A. Olmsted Manager Plastic Machinery Engineer	Injection Blow Foam Vacuum
PLASTICS MACHINERY INC., (AGENTS) 205 Torbay Road, Unit 7A Markham Ontario L3R 3W4 416-495-6677	Mr. R. A. Harris President	Injection Blow Extrusion Vacuum Auxiliary

PLASTICS PROCESSING MACHINERY
MANUFACTURERS AND AGENTS (continued)

P.S.C. CONTROLS LTD., 1980 Monterey Laval Quebec H7L 3S3 514-687-2710	Mr. P. Latraverse President	Load Management Controllers
REIFENHAUSER KG Spicher Strasse D-5210 Troisdorf-Seiglar Federal Republic of Germany	Herrn K. Krumm Manager Research Dept.,	Extrusion
SOLID CONTROLS INC. 6925 Washington Ave.,S Minneapolis Minnesota 51435 612-941-6110	Mr. J. Rodgers Vice-President	Process Controllers
STOKES DIVISION PENNWALT CORP., 5500 Tabor Road Philadelphia Pennsylvania 19120 215-289-0100	Mr. R. Schillinger	Injection Compression Transfer
TEMPFORM DIV.OF SPROULE PLASTICS MACHINERY (AGENTS) 83 Galaxy Blvd. Unit 8 Rexdale Ontario M9W 6A4 416-675-2740	Mr. D. Sproule President	Thermoform Blow Injection Compression Auxiliary
WHITLOCK IND., 23231 Industrial Park Dr. Farmington Hills Michigan 48024 313-477-7100		Dryers Auxiliary

APPENDIX C

PLASTICS RESIN MANUFACTURERS

The following list includes only those firms who assisted this survey by supplying energy related information.

APPENDIX C

PLASTIC RESIN MANUFACTURERS

The following list includes only those firms who assisted this survey by supplying energy related information. It is provided solely to recognize this assistance and in no way implies any sort of recommendation.

For a complete list of plastic resin producers, please consult the Canadian Plastics Directory and Buyers' Guide (Southam Press) or Modern Plastics Encyclopedia (McGraw Hill).

FIRM & ADDRESS	CONTACT
BASF CANADA LTD., 5850 Cote de Liesse Montreal Quebec H4T 1C1 514-341-5411	Mr. S. Bober
BAYER CANADA INC., 1355 Aerowood Rd. Mississauga Ontario L4W 1C2 416-625-6110	Mr. R. Maraghi Manager Plastics
BORG-WARNER (CANADA) LTD., P.O. Box 10 Cobourg Ontario K9A 4K2 416-372-6801	Mr. R. Chick Resin Manager
DOW CHEMICAL CANADA INC., 170 Atwell Drive Rexdale Ontario M9W 5Z5 416-675-7374	Mr. J.H. Shaw District Sales Manager Plastics
DU PONT CANADA INC., P.O. Box 3500 Kingston Ontario K7L 5A1 613-544-6000	Mr. S.Y. Sourour Sales Technical Manager Plastics Division

PLASTIC RESIN MANUFACTURERS (continued)

ESSO CHEMICAL CANADA 2300 Yonge St., Toronto Ontario M5W 1K3 416-488-6600	Mr. J. Douglas Manager Feedstock Energy & Technical Affairs
B.F. GOODRICH CANADA INC., 409 Weber St. W Kitchener Ontario N2G 4J5 519-742-3641	Mr. F.W. Hovey Director Marketing
REICHHOLD LTD., 1919 Wilson Ave., Weston Ontario M9M 1A9 416-742-0262	Mr. Y. Baillargeon Product Manager
SHELL CANADA CHEMICAL CO., 480 University Ave., Toronto Ontario M5G 1V2 416-597-7814	Mr. B. Ward Technical Manager Polymers
UNION CARBIDE CANADA LTD., 123 Eglington Ave.,E Toronto Ontario M4P 1J3 416-488-1444	Mr. R. MacElwee Market Manager

APPENDIX D

ASSOCIATIONS, INSTITUTES AND PROCESSORS IN EUROPE WHO WERE INTERVIEWED AND WHO SUPPLIED INFORMATION TO ASSIST THIS STUDY.

APPENDIX D

ASSOCIATIONS AND PROCESSORS INTERVIEWED IN EUROPE

ASSOCIATION OF PLASTICS MANUFACTURERS IN EUROPE (APME)
Avenue Louise 250 Box 73
B-1050 Brussels
Belgium

Mr. P.G. Claus
Executive Secretary

Note-This is the Association of Plastic Resin Producers in Europe

GESAMTVERBAND KUNSTSTOFFVERARBEITENDE INDUSTRIE E.V. (GKV)
Am Hauptbahnhof 12
6000 Frankfurt/Main 1
Federal Republic of Germany

Dr. R. Ackermann
General Manager

Note-This is the Association of Plastic Processors

INSTITUT FUR KUNSTSTOFFVERARBEITUNG (IKV)
Pontstrasse 49
D-5100 Aachen
Federal Republic of Germany

Herrn Prof. D.-Ing.G. Menges
Director

Note-This is the Research Development & Training Institute for the Plastics Processing Industry.

VERBAND DEUTSCHER MASCHINEN-UND ANLAGENBAU E.V. (VDMA)
Fachgemeinschaft Gummi-und Kunststoffmaschinen
Lyoner Strasse 18 P.O. Box 710109
6000 Frankfurt/Main 71
Federal Republic of Germany

Dr. P. Spamer
Director

Note-This is the Plastic Processing section of the Machinery Association.

ASSOCIATIONS AND PROCESSORS INTERVIEWED IN EUROPE (continued)

PROCESSORS

HELMITIN GMBH Postfach 1961 6780 Pirmasens Federal Republic of Germany Herrn Klaus Klan	Extrusion
KAUTEX WERKE REINOLD HAGEN AG 3 Holzlar 5300 Bonn Federal Republic of Germany Dipl. Ing. (FH) R. Zipper VDI	Blow Molding
FRITZ ALBERT RIEGLER KG Postfach 1166 6101 Neider-Ramstadt Federal Republic of Germany Herrn Alfred Schaffner	Injection

APPENDIX E

This appendix contains a list of further reference articles and books on energy conservation related subjects.

FURTHER READING REFERENCE

ENERGY RELATED ARTICLES AND BOOKS

Advances in Materials Processability R.L. Wilder and A.Brockschmidt Associate Editors	Plastics Technology August 1982
Are You Missing The Boat on Injection Molding Productivity? T.M. Roder, Technical Consultant DuPont Co., Wilmington, Del.	Plastics Technology September 1982
CAD/CAM Broadens Its Appeal J.K. Krouse, Staff Editor	Machine Design April 1982
CAD/CAM - What It Will Mean To You R. Wilder, Associate Editor	Plastics Technology April 1982
Control Rising Energy Costs Now -Improve Profits Forever W. Witbeck	Ontario Hydro October 1981
Cutting Energy Costs-Plastics Processing National Economic Development Office London, England	Report # 1
Energy Conservation Source Book Maclean-Hunter Ltd.,	Modern Power and Engineering April 1979
Energy Considerations in Screw Processing of Thermoplastics R.E. Nunn and G.A. Kruder	S.P.E.National Technical Conference Cleveland November 1980
Energy Efficiency Is Hard To Pin Down A.Von Hassell, Associate Editor	Plastics Technology April 1979
Energy Efficiency: Don't Overlook Big Savings Potential H.El-Amin, Assistant Editor	Plastics Technology October 1981
Energy Efficient Motors Energy Conservation and Utilization Division	Ontario Hydro 1981
Energy Management Handbook Wayne Turner	John Wiley and Sons 1982

Energy Requirements For the Production of Injection Molded Parts Dipl.-Ing H. Naetsch and W. Nickolaus	Plastverarbeiter (in German) January 1981
Energy Savings on Injection Molding Machines - How Far Will It Go? H. Kanno, First Engineering Dept., Toshiba Machine Co., Ltd.,	Japan Plastics Age July-August 1982
Energy Use In the Plastics Industry The Rubber and Plastics Research Assoc.,	Report #17 1980
Industrial Energy Conservation Handbook -First Steps to Energy Conservation -# 1 Guidebook -# 2 Heating,Cooling and Lighting -# 3 Process Design and Heat Recovery -# 4 Production Optimization -# 5 Combustion Control -# 6 Steam and Compressed Air -# 7 Transportation and Delivery -# 8 Efficient People Moving -# 9 Office Practices -#10 Motivation and Participation	Dept.,of Energy,Mines and Resources 580 Booth St., Ottawa, Ontario K1A 0E4
Misapplications of Energy Management Systems - How to Avoid Them T. Fenimore	Engineering Digest June 1982
Monitoring or Controlling-The Microprocessor Sets the Pace In Injection Molding	European Plastic News December 1981
Progress In Extrusion Technology K.Krumm, Manager Research Dept., Refenhauser KG.	Ausplas Conference July 1982
Process Controls: How You View Them M. Hartung, Associate Editor	Plastics Technology August 1981
Processing 1982 - A Special Report	Modern Plastics April 1982
Putting More Profit Into Processing F. Hall, Senior Editor	Plastics Engineering September 1980
Reducing Energy Costs In the Plastics Industry (can be obtained by contacting The Society of the Plastics Industry of Canada)	The Society of the Plastics Industry Inc. New York, N.Y.

State of the Industry - A Special Report	Modern Plastics June 1982
Why Solid State Controls For Auxiliary Equipment R. Wilder, Assistant Editor	Plastics Technology October 1981

APPENDIX E.1.

The following Government incentive programs are available at the time of publication of this report.

Listed below are Federal Government incentive or assistance programs involving Energy Conservation. We have listed only those programs we believe to be of interest to plastic processors.

- Atlantic Energy Conservation Investment Program (AECIP)
- Canada Oil Substitution Program (COSP)
- Class 34 Energy Conservation Equipment Fast Write-Off
- Conservation and Renewable Energy Demonstration Program
- Development and Demonstration of Resource and Energy Conservation Technology (DRECT)
- Energy Conservation Research and Development
- Industrial Conservation Task Force Program
- Industrial Energy Research and Development (IERD)
- Industrial Energy Conservation Handbooks (ENER$AVE)
- Microelectronics Support Program (MSP)
- National Energy Audit Program (NEAP)
- Propane Vehicle Conversion Program
- Support for Technology Enhanced Productivity Program (STEP)
- Truck Programs

Space does not permit full explanation of each program. We recommend contacting Energy Mines and Resources at the address below for full explanation brochures on any program that is of interest to you.

DEPARTMENT OF ENERGY MINES AND RESOURCES
580 BOOTH STREET
OTTAWA, ONTARIO
K1A 0E4

APPENDIX F.1.

HEAT RECOVERY

1. Calculating Heat-Exchanger Capacity for A Heat Recovery System.
   Roger F. Merril Phillips Chemical Co.,
   Bartlesville, Oklahoma U.S.A.
   Reprint from Plastics Engineering August 1979

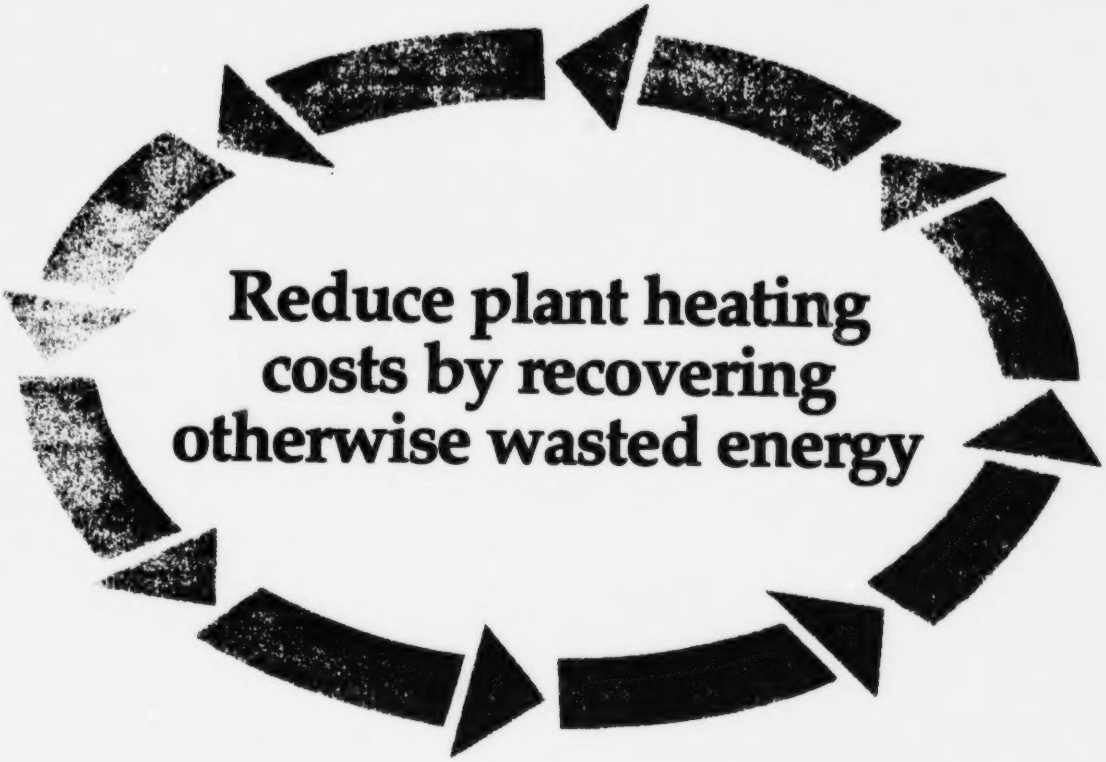
2. Reduce Plant Heating Costs By Recovering Otherwise Wasted Energy
   Donald C. Williams Application Engineering Corp.
   Elk Grove Village, Illinois, U.S.A.
   Reprint from Plastics Engineering February 1979

3. Why Not Use Your Cooling Tower to Heat Your Plant?
   Tom Benson Application Engineering Corp.,
   Elk Grove Village, Illinois, U.S.A.
   Reprint from Plastics Technology.

4. Heat Pipe Air Preheater (partial reproduction only)

   H.N. Franklin, Ph.D., Project Manager

   Foster Wheeler Energy Applications Inc., Livingston, N.J.



Reduce plant heating costs by recovering otherwise wasted energy

Most of the space-heating requirements for plastics processing plants can be met by salvaging the heat generated by the machinery. One plant met 75 percent of its heating needs and saved $90,000.

By Donald C. Williams
Application Engineering Corp.
Elk Grove Village, Ill.

Recovery and recycling of otherwise-wasted energy generated by the operation of plastics-processing equipment—energy which would otherwise be wasted—can help many plants cope with possible reductions or interruptions of their gas and oil supplies and with constantly rising fossil-fuel costs.

The heat extracted by cooling and chilling equipment from molding machines and their hydraulics, and the plastic itself, can supply a substantial percentage of the total space-heating requirements of a large number of processing plants, and in some cases can completely eliminate the need to use any other type of space heating except during periods when plant processes are not operating.

The water-to-air, heat-pump chiller used extensively in plastics plants offers a practical, immediately available method for converting this valuable energy into virtually cost-free heating of manufacturing and warehouse areas.

Cost savings can be impressive for plants of all sizes. A small processing firm in the Midwest is recycling the energy from six injection-molding machines to provide heat for a 6400-square-foot plant. This is done throughout the plant's three-shift, five-day-week production schedule and when the plant operates on weekends. The heat recycled by two 15-ton-capacity heat-pump chillers is equivalent to the effective heat from burning 636 cubic feet of natural gas per hour at a cost of about $1.33 per hour or $160 per week during the peak of the heating season. Annual fuel savings for this relatively small plant total about $1000.

For larger plants, dollar savings can be substantial. A plastics processor in the Upper Midwest saved over $90,000 in the cost of space heat by using heat-pump chillers for the space heating of about 220,000 square feet of floor space.

Chiller operation

Heat-pump chillers are unidirectional heat pumps that remove heat from a coolant and discharge it into the ambient air. Thus chillers in this phase of the cooling cycle operate as space heaters. Used in a manufacturing process, they continuously recirculate coolant through processing machinery.

A schematic diagram of a single heat-pump chiller is shown in *Fig. 1*. Coolant that is still warm, either water or ethylene glycol and water, returning from the process enters a reservoir. The reservoir and a coolant pump are in a separate housing that serves several chiller modules.

The coolant is pumped by a centrifugal pump through a refrigerant-to-water heat exchanger, where it is cooled before returning to the process. The refrigeration circuit is a standard air-cooled refrigeration system.

Heat-pump chillers often are suspended from plant ceilings. During the summer months, when heat is not needed, dampers are adjusted to re-direct the warm air out of the plant through the roof.

A heat-pump chiller with a refrigeration capacity of 15 tons consumes in one hour 22 kilowatts or 75,000 Btus of energy. The chiller extracts 180,000 Btus per hour from the coolant. Added to the 75,000 Btus used to operate the heat-pump chiller, a total of 255,000 Btus per hour is available for recycling as space heat.[a]

Thus filtered plant air at a temperature of 75°F, when fed through the heat-pump chiller at the rate of 12,000 cubic feet per minute, will be raised to 95°F, after which it is blown into the plant.

Energy amplification

The described heat-pump chiller acts as an energy multiplier as the input to the heat pump is 75,000 Btus per hour of electrical energy, and the output is 255,000 Btus per hour of heat energy. It amplifies the input energy by 340 percent.

Using the heat-pump chiller to heat a plastics plant is an ideal application for it because the coolant from which it extracts heat is at a relatively high temperature (generally 60 or 70°F) and is available the year round. Moreover, the heat source is constant (as long as the plastics process is in operation) and at a temperature at which the heat pump can operate at maximum efficiency.

Energy amplification can be translated into dollars and cents in several ways. Consider the cost of operating a 22-kilowatt heat-pump chiller to be about 3 cents per kilowatt hour or 66 cents per hour. Because of energy amplification, this 22 kilowatt-hour input yields an output of 75 kilowatt-hours for the input cost of 66 cents per hour. Dividing 75 kilowatts into 66 cents gives us a cost of 0.8 cent per kilowatt-hour. Thus the cost of electricity to heat the plant is reduced by 71 percent [(3 − 0.88)/3 × 100 = 71 percent]. Translated into an hourly cost basis, the electricity to heat the plant would be 66 cents an hour if the heat pump is in use.

Compare this with the cost of providing an equivalent amount of heat using fuel oil or natural gas. Since these fuels are only 80 percent efficient, it is necessary to produce an output of 255,000 Btus per hour to generate 318,750 Btus per hour input. To do so would require 2.3 gallons of heating oil or 319 cubic feet of natural gas per hour. At a fairly representative cost of 40 cents a gallon, oil heat would cost 92 cents an operating hour. At an average cost of 25 cents per 100 cubic feet, gas heat would cost 80 cents for an hour of operation.

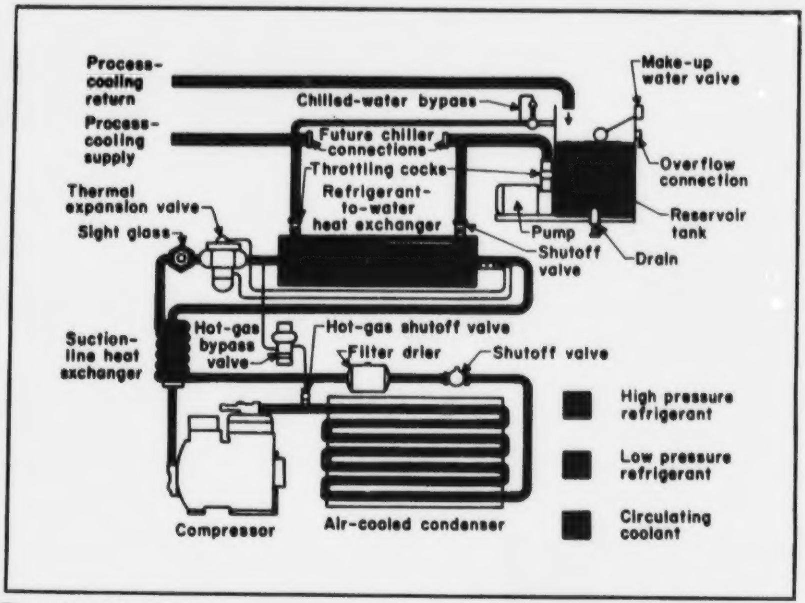

Process-cooling return
Process-cooling supply
Chilled-water bypass
Make-up water valve
Future chiller connections
Throttling cocks
Overflow connection
Thermal expansion valve
Refrigerant-to-water heat exchanger
Reservoir tank
Sight glass
Pump
Drain
Shutoff valve
Hot-gas bypass valve
Hot-gas shutoff valve
Suction-line heat exchanger
Filter drier
Shutoff valve
High pressure refrigerant
Low pressure refrigerant
Circulating coolant
Compressor
Air-cooled condenser

Figure 1. Schematic diagram showing operation of a typical heat-pump chiller. Circulating coolant is pumped from processing machinery via reservoir tank to refrigerant-to-water (or ethylene glycol and water) heat exchanger and back to machinery. Process heat passes from the heat exchanger to a refrigerant loop, which provides additional heat from a compressor. Combined heat passing through the condenser is transferred to cooling air blown over condenser coils to heat the plant.

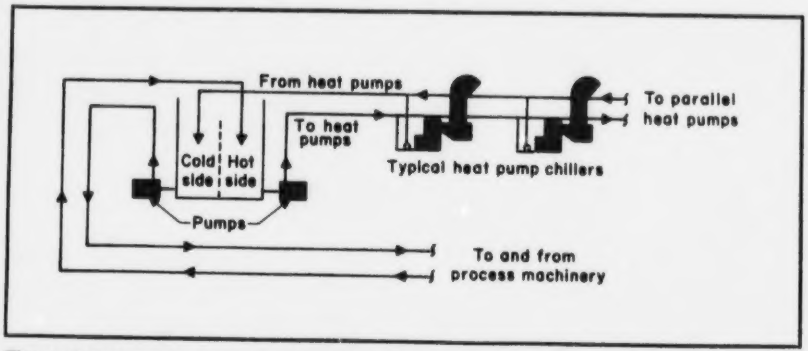

From heat pumps
To parallel heat pumps
To heat pumps
Cold side
Hot side
Typical heat pump chillers
Pumps
To and from process machinery

Figure 2. Schematic diagram of a heat-pump chiller system. Four systems are used in the installation, each containing two pumps and from 3 to 13 heat-pump chillers.

Practical application

The practical consequences of these savings are demonstrated dramatically in the plant that saved more than $90,000 on space heating by using heat-pump chillers to supply most of its heating needs.

The total area of the plant, located in a 7300-degree-day[b] area is about 220,000 square feet. *Figure 2* is a schematic diagram of a heat-pump chiller system that is used to provide cooling for the molds, the hydraulic systems of the injection-molding machines and the air compressors.

There are four such systems in the installation and each of them contains from 2 to 13 heat pumps, 25 in all. The heat-pump chillers in each system are connected in parallel to a common process-water reservoir and pump. In each of these systems there are two pumps. One pumps the coolant from the cold side of the reservoir to the process and back to the hot side of the reservoir. The other pump then pumps the coolant through the refrigeration system and back to the cold side of the reservoir. The system provides 450 tons of refrigeration capacity, or 5,400,000 Btus per hour of cooling/heating.

These heat-pump chillers operate 24 hours a day, six days a week, primarily to supply the process-cooling

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[a] Because the unit is located in the space of the plant, all energy input to the unit is ultimately dissipated into that space as heat.

[b] Degree-day: Difference between 65°F and the daily mean temperature when the latter is less than 65°F.

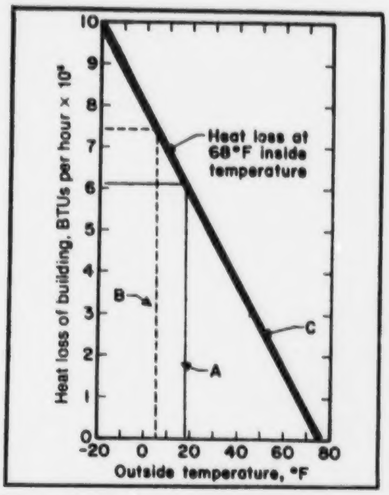

Figure 3. Heat losses of a plant at 70°F for a given range of outside temperatures. A. Chillers with heating output of 6,024,000 Btus per hour can maintain 70°F inside temperature with outside temperatures of as low as 15°F. B. Chillers with heating output of 7,440,000 Btus per hour can maintain same inside temperature with outside temperature down to 4°F.

requirements, but they also provide most of the space heat for the plant when it is in production.

Calculating heat losses

The method used to determine how much of this building's total heating requirements can be handled by the heat pumps can be applied to any plant. First the heat loss of the building is calculated, based on the building's construction, including insulation, wall, roof and floor area, ventilation requirements, and weather data in the geographical location.[c]

With heat-loss data and recoverable heat known, a graph as shown in *Fig. 3* can be plotted, showing the heating **requirements that would be needed to equal the heat losses of the plant in order to maintain an inside temperature of 70°F over an outside temperature of −15°F to 70°F.** ***Figure 3*** **also shows the amount** of heat provided by the heat-pump chillers during the 1975-1976 winter and the amount of heat provided by the systems when additional heat-pump chillers were added for the following winter of 1976-1977. The initial installation could deliver **6,024,000 Btus per hour, or enough heat to supply the complete requirements of the plant to an outside temperature of 15°F. The final installation could deliver 7,440,000 Btus per hour and handle the building heating requirements to an outside temperature down to +4°F.**

Table 1. Fuel savings for 1976-1977 heating season.

Month	Estimated oil requirements without heat pumps, gallons[a]	Estimated oil costs without heat pumps, dollars	Actual natural gas requirements with heat pump, therms	Actual natural gas cost with heat pumps, dollars
September	7,237	2,895	126	26
October	19.299	7,720	1,267	227
November	32,808	13,123	3,485	576
December	48,006	19,202	6,026	973
January	55,725	22,290	8,886	1,419
February	34,738	13,895	5,781	935
March	24,124	99,650	2,664	448
April	12,303	4,921	3,410	565
May	3,136	1,254	1,140	204
June	2,412	965	322	60
July	482	193	51	13
August	966	386	121	25
	241,236	96,494	33,279	5,471

[a] Based on heat-loss formula for buildings in The Handbook of Air Conditioning, Heating, and Ventilating. An 80-percent burner efficiency was used, based on No. 2 fuel oil at 40 cents per gallon.

Table 2. Comparison of heating costs of operating heat-pumps vs water-cooled chiller and cooling tower/oil-heating system during 1976-1977 winter.[a]

Item	Costs, dollars	
	Heat-pump-chiller systems	Water-cooler chiller and cooling-tower/oil-heating system
Electric power to run equipment[b]	110,023	57,506
Space heating costs	5,471[c]	96,494[d]
Electric costs for space heating	1,620	3,188
Make-up water and sewer costs[e]	—	5,036
Water-treatment costs[f]	—	7,590
	117,119	169,814

[a] Degree days were 8484 during 1976-1977 season.

[b] Based on power and light rate in effect during 1976-1977 season.

[c] Actual gas consumption and cost based on power and light rate including fuel adjustment and excluding sales taxes.

[d] Estimated oil consumption if heat pumps were not used. Cost is based on a rate of 40 cents per gallon for No. 2 fuel oil yielding 140,000 Btus per gallon. (Natural gas unavailable in area in required quantities.)

[e] Negligible cost in heat-pump-chiller systems.

[f] No costs in heat-pump-chiller systems, which are closed loops.

The winter of 1976-1977 was exceptionally cold. There were about 8500 degree-days that winter instead of the normal 7300 degree days. Temperatures in the Upper Midwest fell below 4°F a number of times. As a result, the plant under discussion had to supplement recycled process heat with heat from gas-fired space heaters. Nevertheless, recycled plant heat supplied 7,440,000 of the 9,550,000 Btus per hour heat-loss requirement on a design day,[d] a little over 75 percent.

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[c] The data is available from a guide published by American Society of Heating, Refrigeration and Air Conditioning Engineers.

[d] The American Refrigeration Institute recommends −15°F as the design temperature for a design day in the geographical area in which the plant is located.

[e] A common measurement of natural gas. A therm equals 100,000 Btus.

[f] **The system provides high-temperature cooling for hydraulics, air compressors, after-cooler cooling, as well as for other equipment. These machines can be cooled with temperatures as high as 85°F. It also provides low-temperature cooling for molds, injection-molding machines, cooling troughs, as well as for certain other equipment. These require coolant below 80°F.**

Avoiding gas shortages

The plant's allocation of natural gas last year was only 53,000 therms,[e] much less than would have been required to heat the plant. Yet this volume of natural gas was sufficient to supplement recycled process heat and to heat the office areas as well. Without the heat-pump chillers, the plant might have had to undergo a costly conversion from gas heat to oil or propane heat.

Since the local gas company indicated that adequate natural gas would not have been available to heat the plant, a cost comparison should be based on the cost of the oil that would have been needed to heat the plant and warehouse in 1976-1977, without heat-pump.

Table 1 breaks down both estimated oil and actual natural gas use on the basis of degree-days per month. Some 241,236 gallons of oil would have been required at a cost of $96,494 taken at 40 cents per gallon.

Because the heat-pump chillers supplied most of the space heat, the plant actually used only 33,279 therms of natural gas at a cost of only $5,471.

On the reasonable assumption that the plant would have had to use oil heat if heat from the heat-pump chillers had not been available, it is clear that the heat-pump chillers saved the plant about $91,000 a year.

Since electric power is needed to operate the heat-pump chillers, whether they provide space heat or not, its cost should be applied to process cooling.

However, other costs should be taken into consideration. *Table 2* compares the operating costs of the heat-pump chiller system with an alternative process cooling-system that might have been installed at the plant, a combination system consisting of a water-cooled chiller and cooling tower.

The alternative system could have provided process cooling at a much lower consumption of electric power—$57,000 as opposed to $110,000. The economy stems from running all of the high-temperature process-cooling requirements on the cooling tower and the low-temperature requirements on a water-cooled chiller.[f] But offsetting the power saving is $96,000 in additional space heating costs because the water-cooled chiller-tower combination does not furnish any space heat. The operating cost of the water-cooled chiller and chiller-tower combination would prove to be more than $50,000 costlier than the heat-pump-chiller installation.

But there is still another alternative. The heat-pump chillers might have been used in combination with a cooling tower. High-temperature and low-temperature cooling requirements could have been run on the heat-pump chillers eight months a year to get the maximum benefit of their ability to recycle process heat. During the summer, low-temperature requirements would continue to be run on the heat-pump chillers while high-temperature requirements would be supplied by the cooling tower.

It was determined that this would reduce the electric power cost by about $20,000. Taking into account the extra costs associated with operating the cooling tower for make-up water and water treatment, this combination of heat-pump chiller and cooling tower would provide space heat and process cooling for about $16,000 less in operating costs than the system that has been considered.

However, offsetting this saving is the cost of the cooling-tower system itself, which would have to be amortized. Plant management elected to operate the heat pumps all year and use the exhaust feature in the summer to improve plant ventilation. □

CALCULATING HEAT-EXCHANGER CAPACITY FOR A HEAT-RECOVERY SYSTEM

Pilot installation confirms the effectiveness of heat conservation even in a small rotational molding oven.

By Roger F. Merrill
Phillips Chemical Co.
Bartlesville, Okla.

Efficient use of energy is becoming increasingly important to plastics processors as the cost of fossil fuel continues to rise while supplies diminish. Operations using natural gas for process heating often lose large amounts of energy as waste heat exhausted into the atmosphere. Now, facing fuel allocations, curtailments, and increasing costs, industry is looking at heat recovery as a means of reducing consumption and expanding operations without the availability of additional fuel supplies.

Most ovens used in rotational molding use gas as their basic fuel.[a] Large volumes of waste heat can be recovered from many of these ovens by using specially designed heat exchangers. This offers the dual benefits of process economy and the conservation of fuel to the processor. The recaptured heat can be used for heating the plant buildings in cold weather, heating water, and for returning preheated air to the combustion chamber of the rotational oven itself.

Rotational molding process

Rotational molding is a simple but highly effective process for molding powdered resins as well as those that are in a liquid state such as plastisols, polyesters, epoxies and acrylics. Complicated shapes, large and small items, square and round objects, thick and thin wall sections, and open-ended products can be produced at low mold costs.

First a cold mold is filled with the powdered or liquid resin, the mold is placed in an oven and rotated simultaneously around two perpendicular axes. During this stage, a uniform layer of resin is deposited on the mold. After sufficient time has elapsed to fuse the resin, and while it is still rotating, the mold is cooled. This can be accomplished with forced cool air, atomized air-water fog, water spray or a combination of these methods. After cooling, the part is removed from the mold and more resin is added to start the cycle again.

Btus and air movement

To keep cycle times at a minimum and to attain even heating are the major goals of the processor using the rotational process. This requires ovens with high heat capacity and air movement. The rating of the oven used here was 1.0×10^6 Btus per hour. Other rotational ovens used in the plastics industry are much larger with oven ratings of at least 8.0×10^6 Btus per hour. Forced-exhaust systems on these ovens are designed to change the air at least three times per minute. This makes large quantities of heat available for heating water or air for various uses in the plant.

See *Plastics Engineering*, February 1979, page 35, for a complete cost analysis of a heat-recovery system.

Basic to the design of any heat-recovery system is the amount of heat available for transfer, determination of which requires measurement of the heat source temperature and flow volume. Initially, in this installation, some assumptions were based upon the manufacturer's ratings of the exhaust fan and an average use-temperature of the rotational molding oven. An exhaust fan of 950 cubic feet per minute at an average air temperature of 550°F would give an estimated 260,000 Btus[b] per hour for heat transfer.

Design aspects

The starting point for the design of the waste-heat-recovery system (*Figure*) was the estimated heat in the exhaust air. The hot-air source in the exhaust is redirected by duct to pass through a 12-by-18-inch exchanger to heat water. The exchanger was sized according to the estimated heat available in the exhaust air; this worked out to the capacity of heating 11 gallons of water per minute from 90°F to 140°F.

A centrifugal water pump rated at 11 gallons per minute with 20 feet of head constantly circulates water through the heat exchanger. Air actuated controls operate dampers in the 10-inch-diameter duct to either direct air through the heat exchanger or exhaust the hot air through the bypass as required to maintain a thermostatically controlled water temperature. The sensing element is located in a 300 gallon hot-water-storage tank which simply acts as a reservoir storing energy for periods of high hot-water consumption, and when the molding machine is not operating. Three hundred fifty feet of 1-1/2-inch pipe was required in the water-circulation system. All pipes and ducts and the storage tank were insulated to minimize heat loss.

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[a] The specific data secured for this article was taken using a small gas-fired rotational oven, the McNeil Rota-Cast, Model No. 600.64.

[b] The number of Btus per hour equals volume of air times density of the air times specific heat of the air times 60 minutes times ΔT.

Exhaust air

Velocity and temperature readings between the exhaust fan and the heat exchanger are needed to quantify heat transfer. An airflow meter was used to measure flow velocities in the exhaust duct as the air passed through the heat exchanger (see *Table 1*).

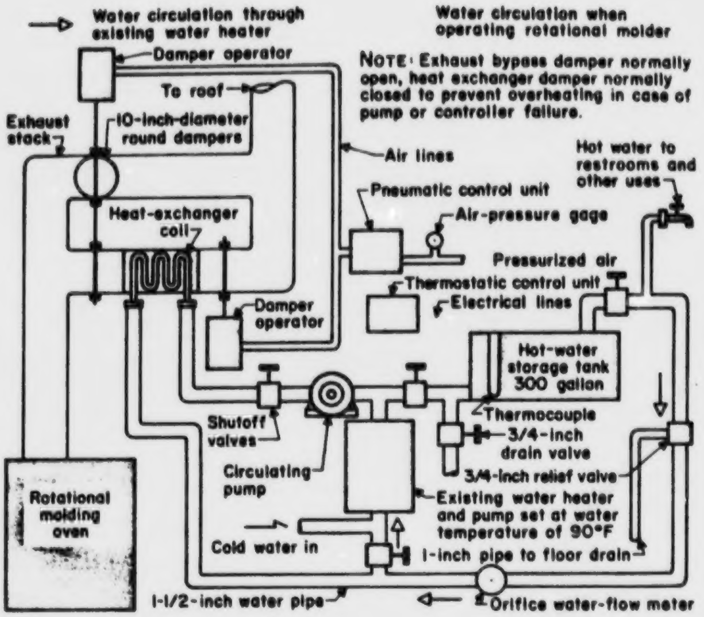
The exhaust fan draws slightly more gas from the oven than is being added by the combustion gases, creating a slightly negative pressure in the oven that causes it to draw room-temperature air into the exhaust duct. This accounts for the observed temperature drop from the oven to the exhaust stack.

Temperature drop of the exhaust air across the heat exchanger was measured by thermocouples monitored on a multipoint recorder. From the air volume and temperature recordings, heat transfer from the exhaust air was calculated for each oven temperature.

Circulating water

Precise measurement of water-flow rate through the heat exchanger was necessary to determine the amount of heat being transferred from the hot air source. Flow rates were constantly monitored at the 1-1/2-inch pipe. The measured flow rate was a constant 13.7 gallons per minute. Temperature readings were taken from thermocouples located near the exchanger in the circulating water. A temperature differential across the heat exchanger was measured at each oven test temperature (*Table 2*).

In most air-to-liquid heat-recovery systems it is difficult to show a balance between the Btus transferred between the air and liquid because of the difficulty of getting accurate airflow measurements across the heat exchanger. The difference noted in this system could have been caused by air leakage past the bypass damper and difficulty in measuring the velocity because of the turbulence created by the exchanger itself. Usually the heat transfer to the water gives more reliable information because of the accuracy of water-flow-rate instruments.


Water circulation through existing water heater
Water circulation when operating rotational molder
NOTE: Exhaust bypass damper normally open, heat exchanger damper normally closed to prevent overheating in case of pump or controller failure.
Damper operator
To roof
Exhaust stack
10-inch-diameter round dampers
Air lines
Hot water to restrooms and other uses
Pneumatic control unit
Air-pressure gage
Heat-exchanger coil
Pressurized air
Thermostatic control unit
Electrical lines
Damper operator
Hot-water storage tank 300 gallon
Thermocouple
3/4-inch drain valve
Shutoff valves
3/4-inch relief valve
Circulating pump
Rotational molding oven
Existing water heater and pump set at water temperature of 90°F
Cold water in
1-inch pipe to floor drain
1-1/2-inch water pipe
Orifice water-flow meter

Schematic diagram of waste-heat-recovery system incorporated in a rotational-molding installation. Flow arrows indicate two modes of operation: A. Heat drawn from oven. B. Heat generated by water heater.

Oven temperature, °F	Exhaust temperature, °F	Corrected air velocity, feet per minute	Air volume, standard cubic feet per minute
400	360	1333	729
500	450	1201	661
600	530	1104	607
700	605	1026	565

Positions		Air-side data		Water-side data	
Oven temperature, °F	Exhaust temperature, °F	Change in air temperature, °F	Heat transferred, Btus per hour	ΔT Water, °F	Heat transferred Btus per hour
400	360	195	102,000	16	110,000
500	450	270	114,000	20	137,000
600	530	350	126,000	25	171,000
700	605	415	129,000	28	192,000

The circulating water

Beginning with 80°F water in the 300-gallon storage tank, the oven was operated at varying temperatures to determine the heating capacity of the exhaust air. The energy requirement to heat 300 gallons of water from 80 to 140°F is about 150,000 Btus. According to the heat-transfer calculations from water-flow rates, this system should be able to heat 300 gallons from 80 to 140°F in about one hour.

The time for heating the water was obtained from the recorder as it monitored the temperature rise of the water. At exhaust temperatures of at least 500°F this system would allow a continuous input of 5 gallons of water per minute at 80°F and would maintain the water temperature in the storage tank at 140°F.

Safety

Safety must be an important consideration when working with high-velocity air at the temperature ranges normally present in rotational molding oven exhausts. In the small rotational oven described an exhaust bypass performs not only an operation function but also a safety function. In the case of pump failure, the exhaust can bypass the exchanger and prevent overheating the stagnant water. Secondly, the damper controls are instrumental in the bypass safety feature. In case the pump fails or is not in operation, the spring-loaded dampers will not operate and are held in their normal positions. Damper position in the bypass is normally open and in the exchange duct, normally closed. Finally, there is a pressure/ emperature relief valve installed in he circulating lines between the torage tank and distribution points.

Costs consideration

As fuel costs continue to rise, efficient use of this resource is becoming critical. Excluding labor, fuel cost alone accounts for over 50 percent of the operating costs of rotational molding machines and this percentage will increase with increasing fuel prices.

Putting the plan into effect

If heat reclamation becomes an option, the most economical application or combination of applications must first be determined. Available options include heating water, preheating combustion air, and comfort heating.

In order to establish how much waste heat is available, measurements must be made of heated waste-air flow, temperatures, and the hours of operation of the rotational oven. From these measurements, calculations can determine how much fuel would be saved by replacing an existing heating source or providing additional heat that would normally require additional fuel. Companies that market heat-recovery units are usually helpful in determining payback and return on investment for a potential installation.

The heat-recovery system for the small rotational oven described was installed[*] primarily for demonstration, not for cost saving, although some saving was realized. The installation of flow devices, temperature recording instruments, and other experimental equipment increased the costs beyond what would normally be expected for an installation of this type.

As an example of yearly fuel savings, if the average temperature of the exhaust air from this rotational molding oven is 530°F, there is approximately 171,000 Btus per hour recovered by heating water. If this hot water is used 24 hours per day for comfort heating during a 200 day heating season and replaces or supplements a gas-fired boiler that is 60 percent efficient, a yearly fuel savings of 1,368,000 cubic feet of natural gas could be expected. At $2 per thousand cubic feet this would save about $2,700 that is normally spent on gas heating.

Applications

Even small installations can save fuel and money. If hot-water consumption exceeds the capacity of the heat-recovery system or if the rotational molder is not in use, the steam heater is utilized. The system provides hot process water and could be incorporated in a conventional run-around system with unit heaters to provide comfort heating.

It is generally recognized that maximum savings occur when this recovered heat is returned to the process, as in an air-to-air recovery system that returns the reclaimed energy to the process by preheating combustion air for a gas-fired oven. Preheating combustion air not only reduces fuel use and increases oven efficiency, it can also stabilize processing temperatures and improve production. Because air increases in volume when heated, specific engineering must be done on sizing combustion air fans and orifices to insure the most efficient burning rate of the fuel being used.

Drying and curing are operations that should recover heat when possible. Resins like nylons that are hygroscopic and must be dried before processing create waste heat that could be reclaimed and returned to the drying operation.

Today, economical heat recovery is not limited to large operations. Because of rising fuel costs and supply problems, any waste heat can be considered as a new source of energy. New equipment and technology can provide many plastics processing plants with the capability of recovering a large percentage of their waste heat. □

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[*] At the Plastics Technical Center, Phillips Chemical Company.

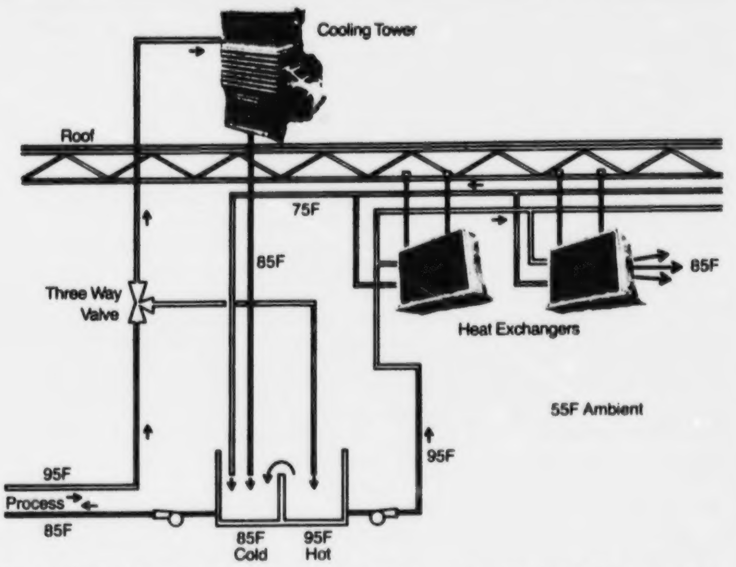


Fig. 1—Payback for use of heat exchangers in the return-water circuit of your cooling tower to heat your plant or warehouse usually ranges from one to three years, depending on what type of fuel is normally used. (W-unit is AEC's trade name for its heat recovery units.)

Why Not Use Your Cooling Tower To Heat Your Plant?

It might seem strange at the onset of the summer months to present an article on how to utilize cooling towers to heat your plant. This article also may seem to be straying somewhat from our traditional theme of presenting the various ways and means by which you can improve your productivity. But when the seasons change and you add up your oil, gas and electric space heating bills, you may be glad to have read the following article. As the author points out, heat exchangers are available that can capture heat from process water before it reaches your cooling tower, providing an efficient and economical source of energy to heat your plant. All types of molders could benefit from this approach.

By Tom Benson, Energy Systems Manager, Application Engineering Corp., an AEC Company

If you're looking for a way to cope with the high cost of space heating, the solution to your problem may be right on the roof of your plant. Chances are your cooling tower is wasting substantial quantities of energy that could be recycled to help heat your warehouse or other areas of your plant. For example, a typical 100-ton (1.5-million Btu/hr) capacity cooling tower can supply space heat equivalent to that provided by $160 worth of natural gas or $290 worth of heating oil *daily*.

This normally wasted heat can be recaptured by installing a heat recovery system in the return-water circuit of the cooling tower, thereby making it possible to utilize the heat removed from process to provide space heat throughout the winter months. If this concept sounds a bit familiar, it's probably because so-called "heat pump" chillers —also designed to recycle waste process heat for space heating—have become a popular option in the past four years or so (see *PT, Sept. '77, p. 101* for an article on the subject). As a more recent development, special heat-exchange equipment has been developed to offer the same economics to processors who use cooling towers instead of chillers (see *PT, Dec. '80, p. 34*).

In effect, the heat recovery unit takes over the process cooling function of the cooling tower whenever space heating is required. As shown in Fig. 1, heated water returning from process machinery is diverted by a three-way valve from its normal path to the cooling tower, and sent to the hot side of the system reservoir. From the reservoir, it is pumped to one or more heat recovery units, which are actually water-to-air heat exchangers suspended from plant ceilings. Heat from the water passes out through radial fins, over which a centrifugal fan blows ambient air. This continuously heated air stream is directed downward to the area to be heated.

Meanwhile, the process water, having given up its heat to the air stream, returns to the cool side of the reservoir, where it is circulated back through the process. For all practical purposes, this system functions as if it were a conventional fossil-fuel-burning hot-air heating system, with one major difference—it doesn't burn any fuel!

By means of thermostatic control of the tower fans and the three-way valve, this system works automatically to provide 100% of design cooling as well as maximum space heating. During the summer months, when there is no need for space heat, the three-way valve will send 100% of the water to the tower; the heat-recovery circulation pump and units are shut off for the summer, allowing the cooling tower to handle 100% of the process cooling function.

The contribution that a heat recovery system can make to total space heating requirements depends on two basic considerations: 1) the quantity of heat (Btu) needed to maintain a warehouse or plant interior at the desired temperature, and 2) the quantity of heat that is available from the cooling tower system under the specific conditions at which it operates. What follows is an examination of how you can determine your space needs and what the economic payback can be for use of a heat recovery unit—typically priced at around $5000—in your operation.

Determining space heating needs Space heating is the process of maintaining the design temperature of an interior area by replacing the heat lost through the walls, windows, doors, roofs and floors and through the ventilating system as a result of air changes. (The term "design temperature" refers to the temperature that occurs less than 1% of the time during the year and is a low-end temperature point used for designing the system.) The quantity of heat lost is a function of the building's construction, the outside temperatures during the heating season and the frequency of air changes needed to ventilate the interior. (In order to simplify the calculations involved in determining the interrelationship of these variables, it is advantageous to assume that there is a relatively standard design of most industrial buildings with respect to heat-loss characteristics.)

Probably the best way to illustrate the relatively simple calculations involved in determining the space heating needs of any industrial building is to go through those calculations for a typical warehouse. Heating your warehouse is an ideal application for the cooling-tower approach since the temperature in your warehouse is generally lower than in your plant and heat extraction is more efficient with a larger ΔT.

As background material, we'll use Fig. 2 and Table 1, which show the relationship between the difference in inside ambient temperature and the winter design temperature for major cities throughout the country.

The specific example will be a warehouse in Buffalo, N.Y., where standard ventilating procedure calls for three complete air changes every four hours (as contrasted with the one or two changes per hour required in areas where people are working continuously, such as production areas).

The design winter temperature in Buffalo is 2 F. Figure 2 shows that the heat loss per square foot of floor area of a warehouse in Buffalo, in which the inside temperature is maintained at 55 F, is 33 Btu/hr on a design day. The total heat loss for the warehouse can be determined by multiplying 33 Btu/hr by the number of square feet of warehouse floor space. In our example, we are assuming a warehouse area of 100,000 sq ft and, therefore, a total space heating requirement of 3.3-million Btu/hr at the outdoor design temperature of 2 F.

Assume that the temperature of the water returning from process is 95 F and the interior of the warehouse is to be maintained at a temperature of 55 F (the conditions shown in Fig. 1). Extrapolating from information in the manufacturer's specifications for the heat recovery unit, we find that it has a cooling capacity of 380,000 Btu/hr and a space heating capacity of 400,000 Btu/hr. (The difference of 20,000 Btu/hr in

Table 1—Winter Design Temperatures

Area	Temperature, F
Albany, N.Y.	−6
Baltimore	10
Boston	6
Buffalo, N.Y.	2
Chicago	−8
Cincinnati	1
Cleveland	1
Denver	−5
Detroit	3
Hartford, Conn.	3
Indianapolis	−2
Louisville, Ky.	5
Minneapolis	−16
Nashville, Tenn.	9
New York City	11
Omaha, Neb.	−8
Philadelphia	10
Pittsburgh	1
St. Louis	2
Salt Lake City	3

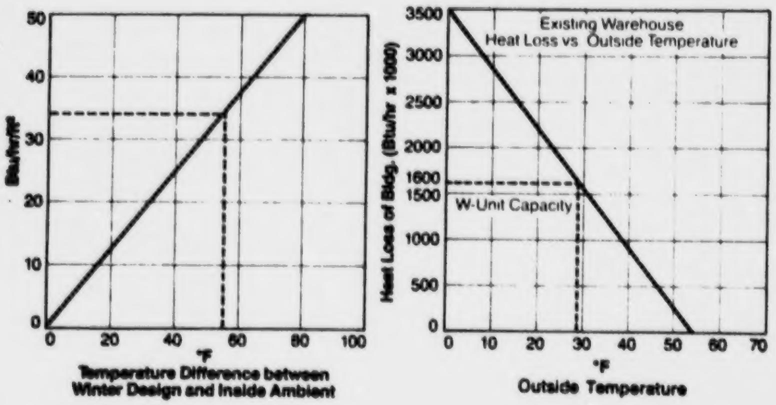
Table 2—Five Year Cash Flow With Heat Recovery Unit

	Year 1	Year 2	Year 3	Year 4	Year 5
Net Annual Fuel Cost Savings	$48,005	$60,322	$75,766	$95,125	$119,386
Net Annual Cash Flow After Taxes	32,070	36,615	43,046	51,693	62,998
Net Cumulative Cash Flow After Taxes	(32,469)[b]	4,146	47,192	98,885	161,882

[a] Internal rate of return on investment, based on averaging cash inflows and based on total equipment and installation costs (after tax credits) over 10 years: 66.4%

[b] Figure in parenthesis refers to a negative amount.

Notes:
1) Depreciation is double-declining balance over 10 years.
2) Annual oil inflation of 25%.
3) Annual electricity inflation of 15%.
4) Both investment tax credit & energy tax credit are included.
5) The fuel savings are estimates based on weather data for "normal" winters at Buffalo, N.Y., and heat-loss calculations. The actual experience could vary from this.
6) Fuel costs used: oil—90¢/gal; electricity—4¢/kwh.
7) A 50% corporate tax is included in cash flow.



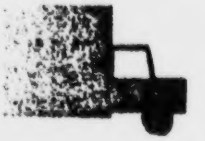


Fig. 2 (left)—The best payback on a heat recovery unit is realized when it supplies about 50% of the total space heating requirements on a design day. (Right)—100% of the space heating requirements are provided for this warehouse when the outside temperature is 29 F.

favor of space heating is due to the conversion of the electric power used to operate the heat recovery unit into heat energy.)

Generally, the best payback on a heat recovery unit is realized when it supplies about 50% of the total space heating required on a design day, as in the example under discussion, where four heat recovery units provide 1.6-million Btu/hr of the needed 3.3-million Btu/hr. As shown in Fig. 2, the four heat recovery units provide 100% of the space heating requirements of the warehouse under discussion when the outside temperature is 29 F.

At lower outside temperatures, the heat recovery units provide a progressively smaller proportion of total space heating requirements. Conversely, as outside temperatures rise above 29 F, the heat available from the heat recovery unit is more than is needed for space heat. This excess heat can be discharged through the roof of the warehouse by means of ductwork installed for that purpose, or through the cooling tower in such a way that the heat recovery unit supplies only that portion of the cooling load corresponding to the space heating that is needed. The cooling tower takes over the remainder of the cooling load and, by its normal operation, discharges unwanted heat to the outside. During the summer, when no space heat is needed, the entire process cooling load is taken over by the cooling tower, which discharges all of the heat extracted from process water in the normal course of its operation. Process-water temperatures can be monitored automatically to govern correct proportioning of water, or conventional room-air thermostats may be used to shut off the heat recovery unit when it is not needed.

Economic analysis On the basis of data available from the U.S. Weather Bureau for an average winter in Buffalo, the heat loss from the plant under discussion has been determined to be 6.86-billion Btu during the course of the heating season, assuming that the plant operates and is heated seven days a week. The recycled heat supplied by the four heat recovery units totals 5.97-billion Btu, which constitute 87% of the total heating requirements. (Although less than 50% of the warehouse's heat requirements are supplied during a 2 F design day, most days during the heating season are considerably warmer than the design day.)

Table 2 shows the cash flow over a five-year period for the warehouse heating system described above. Although the table is self-explanatory, it is worth noting that two tax savings are available on heat recovery units—1) the regular 10% investment tax credit, and 2) the special 10% energy tax credit on heat recovery equipment. Although purchasing the equipment outright would generate an internal rate of return of 66.4%, leasing the equipment might be even more suitable to the financial requirements of some plants, inasmuch as savings on fuel costs can pay most or all of the leasing costs. Payback for these units usually ranges from one to three years, depending on what type of fuel is normally used for space heating. If you use electric heating, the payback time is apt to be more like one year vs. two years for oil and gas heating.

Additional savings (not included in Table 2 for the sake of simplicity) result from reduced operation of the cooling tower—specifically, reduced water consumption due to less evaporation, windage, bleed-off losses, and use of water treatment chemicals, plus lower consumption of electric power since the tower runs less often. □□

BACKGROUND

Heat Pipe

A heat pipe is a device which exhibits a high thermal conductance. This high conductance is a result of the large latent heat of vaporization and condensation. Figure 1 illustrates the two types of heat pipes. Both contain a working fluid specifically selected for the operating temperature range. Heat is absorbed over the evaporator portion of the heat pipe vaporizing the internal working fluid. The vapor is transported to the condenser portion where the fluid is then returned to the evaporator and the cycle is repeated. Types of heat pipes differ according to the method used to transport the working fluid.

The thermo-syphon heat pipe uses gravity, buoyancy, and vapor pressure forces to transport the phases of the working fluid. It requires the heat source to be below the heat sink; that is, the evaporator section must be below the condenser section. The vapor generated in the evaporator travels upward due to buoyancy and the lower pressure in the condenser section. In the condenser the vapor is condensed to a liquid, thereby also reducing the pressure. The liquid returns to the evaporator by gravity. The thermo-syphon heat pipe can be made to function efficiently within a range of orientations of approximiately 7 to 90 degrees from the horizontal.

The capillary action heat pipe does not require gravity to return the condensate to the evaporator section. As the name implies, capillary action is used instead. This heat pipe contains an internal element known as a wick which spans the length of the pipe. The wick may be gauze, wire mesh, or other materials which provide closely spaced longitudinal paths for returning the condensate. The path spacing is chosen based on the working fluid to obtain high capillary forces. There are no orientation restrictions associated with this type of heat pipe.

Foster Wheeler uses the basic thermo-syphon heat pipe. This choice was made because of its simpler construction and higher power handling capacity. One additional feature has been added. The entire internal surface of the heat pipe is roughened. This assures high heat transfer efficiencies when the heat pipe is in operation. The surface roughening plays an important part in assisting the heat transfer process in both the evaporation and condensation modes by increasing the internal heat transfer surface effectiveness. It should also be noted that the heat source and sink do not have to be adjacent to each other. If a gap exists, it can be spanned by an adiabatic (non-heat transfer) section of the heat pipe. This adiabatic region is created by externally insulating the appropriate section of the heat pipe.

Applications

Heat pipes have been used successfully in a variety of applications. Development is in progress to expand their use to many new applications. Current applications include capillary heat pipes in zero gravity satellite cooling systems to remove heat generated by the electronic equipment. A more down to earth application is in heating and ventilating systems. In the winter, heat is recovered from the exhaust air to preheat incoming fresh air. In summer, the process is reversed to precool the fresh air prior to airconditioning.

Industrial applications include steam condensers, flue gas reheaters, and air preheaters. The steam condenser, discussed in more detail in Reference 1, finds application where cooling water supplies are limited. The steam surrenders its latent heat at the bottom of the bundle, and cooling air is blown over the top of the heat pipes to provide the heat sink. In the flue gas reheater, heat is extracted from the flue gas prior to its entering scrubber modules. This heat is transferred to the flue gas exiting the scrubbers to provide sufficient buoyancy to disperse the gas as it enters the atmosphere. Air preheater applications are generally divided into two categories. The first is to provide preheat capability to new or existing boiler and process heater installations. The second is retrofitting exisiting air preheater installations to increase thermal efficiency. Operating experience of heat pipe air preheaters is described in Reference 2.

Airheater - General Arrangement

The general arrangement of the heat pipe air preheater is shown in Figure 2. In the case of the horizontal unit, the tubes are inclined at an angle of about 10 degrees with the lower portion of the heat pipes located in the hot flue gas. A thorough analysis of all factors, such as loads, thermal deflections, etc., for steady state and transient conditions led to the conclusion that the design would employ the "hot box" principle where all insulating materials are placed on the outside of the unit. This avoids low casing metal temperatures which could lead to accelerated corrosion.

Airheater - Design

A schematic of an airheater is shown in Figure 3. Each heat pipe is manufactured from two steel tubes with welded finning for extended outside surface. Internal roughening improves the internal heat transfer performance. The two tubes are joined at the plate which divides the gas and air flow. Joining is accomplished by welding the tubes to each other and the divider plate. This forms a leak-tight joint between the air and flue gas as well as the heat pipe. The divider plate transmits the weight of the heat pipe bundle to support steel through the reinforced casing.

End caps are welded to the heat pipes which permit each pipe to be evacuated and filled with a premeasured charge of working fluid. The composition of the working fluid is varied for the particular application. The fluids used are non-toxic hydrocarbons for which considerable test data and operating experience have been assembled. The tubes are sealed and leak-tested under vacuum conditions prior to a second final sealing.

Proper flow distribution is assured by having baffle plates at each end of the bundle. Additional plates may be added, if necessary, to eliminate any potential flow induced vibration.

In operation, the preheater casing is hotter than the tube bundle on the gas side, the bundle being hotter than the air side casing. This thermal expansion mismatch is accommodated by properly positioning the outermost baffles over the unfinned ends of the heat pipes allowing the bundle and casing to grow independently. Finite element techniques are used to ensure that structural deflections will not interfere with thermal expansion.

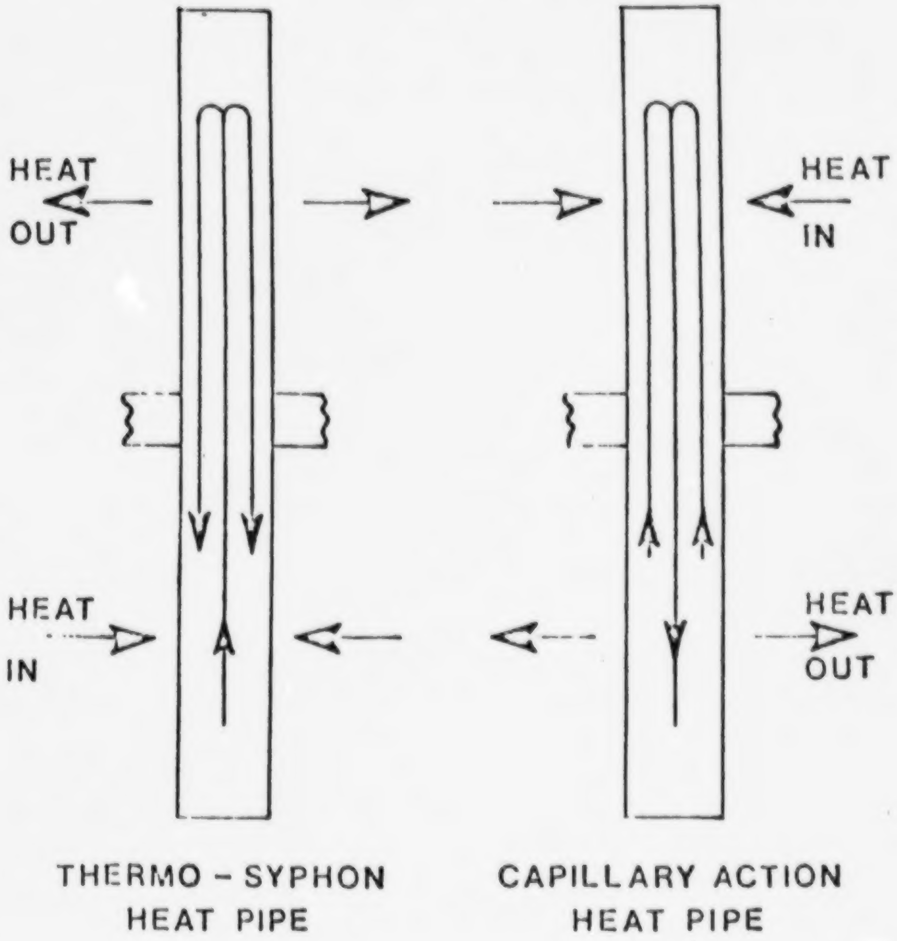
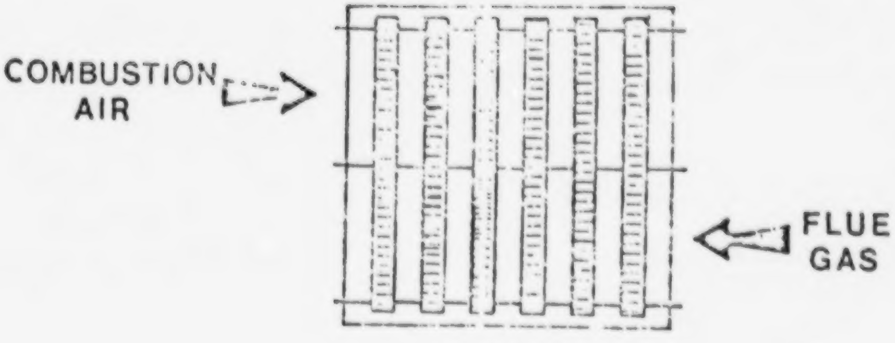
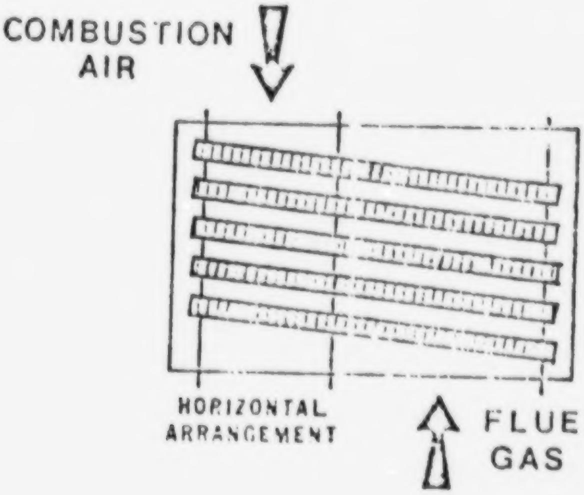

HEAT
OUT
HEAT
IN
HEAT
IN
HEAT
OUT
THERMO - SYPHON
HEAT PIPE
CAPILLARY ACTION
HEAT PIPE

FIGURE - 1
HEAT PIPE CONCEPTS


COMBUSTION AIR
FLUE GAS

VERTICAL ARRANGEMENT


COMBUSTION AIR
FLUE GAS

HORIZONTAL ARRANGEMENT

FIGURE - 2
GENERAL ARRANGEMENTS

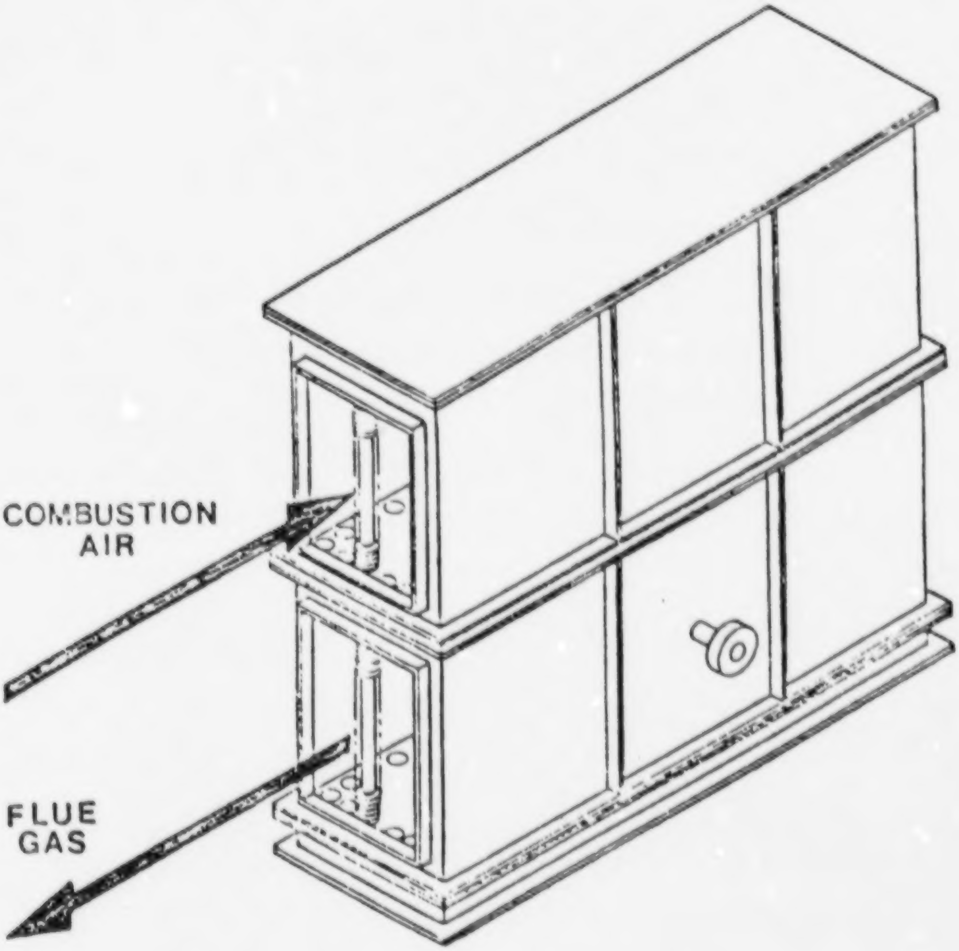

COMBUSTION
AIR
FLUE
GAS

FIGURE 3
AIR PREHEATER SCHEMATIC

APPENDIX F.2.

MAINTENANCE

Note- The equipment listed under Item 2 is illustrated to demonstrate a useful maintenance instrument. There are other brands of similar equipment and its appearance here does not imply an endorsement.

1. Maintenance A Key to Energy Savings
   Janet Lane
   Reproduced from Canadian Chemical Processing
   May 1982

2. A Portable Non-Contact Infrared Thermometer
   Linear Laboratories
   P.M.I. Resource Services Inc.,
   Markham, Ontario

Plant Maintenance

Maintenance a key to energy savings

Downtime is a good time to begin an energy conservation program. A proper maintenance schedule is a very cost-effective means of achieving savings that might easily be overlooked

by Janet Lane

Major energy savings can be made through plant "housekeeping". A regular plant maintenance program focussing on energy conservation can result in significant savings with little capital investment. Education of plant personnel is the key. Each person can contribute to management of energy resources. Some energy wasters are obvious — hot water leaks, lighting levels too high, leaving heating and lighting on when the plant is not occupied — but others may be less apparent, such as: boilers operating at less than peak efficiency, oversized drives, or faulty steam traps.

Developing a maintenance program is the first step in locating trouble spots. An analysis of the plant's energy usage should form the basis of the program, delineating problem areas or sites where most energy savings could be realized. Every plant offers different opportunities to optimize energy reductions. Effectiveness is related to the amount of detail in an energy audit and monitoring program.

A regularly-scheduled inspection of all operating areas is a necessity. The inspection should record each preventative maintenance "action" and frequency of performance, whether daily, weekly or monthly. For example, temperature and pressure in boilers should be checked daily, steam traps daily to weekly (depending on whether they are high or low pressure type) rotating equipment and drives must be checked semi-annually for vibration and alignment. Lights must be cleaned frequently. Once the plan has been established, the actions must be followed up and recorded. The program is monitored so that progress in energy reduction can be evaluated, and the effectiveness of each measure discovered.

Building envelope

In establishing the energy management program, the actual building envelope should be tackled first. Conspicuous energy losses can be found in window and door leaks, overheating or excessive air conditioning. Reasonable temperature limits should be set, such as heating only to 65°F and cooling to 80°F during working hours. Nighttime and weekend temperatures should be set back even further. Can lighting and heating levels be reduced in seldom-used areas? Lights normally left on can be turned down or off in off-shift periods. "Task lighting" should be used wherever possible.

Proper maintenance of ventilating systems can save significant amounts of energy, and can also keep the employee more comfortable. Checking dampers and ductwork for leaks or blockage can eliminate drafts in the workplace. A fan in poor working condition can create excessive noise and insufficient ventilation for the personnel, as well as be an energy waster. Monitoring HVAC systems may require an investment in controls. These may be as simple as thermostats and timers, or as complex as computer control. In such an area where large energy savings can be made, the expense and effort are likely worth it.

Boilers

Steam compression management and control of combustion operations is another area of high savings easily attainable. Maintenance improvements are noticeable quickly in decreased energy consumption. Combustion equipment such as process-fired heaters and furnaces, fossil-fueled system generators and boilers, will benefit from an air-control program. Firing a boiler with the lowest possible excess air is the most efficient way to operate a boiler. Just as important, the combustion air must not be reduced to an extent that unburned fuel exits up the stack. Monitoring stack gas temperatures is an indicator of boiler performance. A boiler will operate at peak efficiency only if regular checks are maintained on controls, gauges and temperatures.

Boiler Optimization

- Check fuel-to-air ratio monthly, reduce excess air to increase boiler efficiency.
- Maintain boiler settings to eliminate excess air filtration.
- Monitor stack gas temperatures monthly for indications of fouling on heat transfer surfaces.
- Check safety and relief valves to avoid failure.
- Remove scale annually.
- Calibrate controls annually.

Steam traps

One of the most productive items to focus on in energy waste prevention is the steam trap, designed to remove condensate and gases from steam lines. The sizing of the trap is important to an efficient system. Oversized traps will waste steam, while undersized traps tend to accumulate condensate. Condensate load and pressure differential are the criteria for properly sizing a steam trap. Faulty traps can cause corrosion problems in valves and pipes, and also great heat losses. This is part of a conservation program where regular inspection is extremely important. Steam traps can fail without warning and a failure must be remedied as quickly as possible.

Compressed air

Compressed air management is important to a plant conservation program. Basic instrumentation is required to gauge the system efficiency. Line leaks and poor compressor performance are apparent with low suction pressures. Frequent checks of compressor discharge temperature will detect leaky valves or piston rings — leaks will raise the discharge temperature. Driving belts, filters and other critical parts of the compressor should be inspected regularly.

Steam and Compressed Air Management

- Check insulation on all steam and condensate lines and on process equipment.
- Repair all sources of steam leakage, eg flanges and high-pressure reducing stations.
- Check and maintain steam traps daily to monthly, depending on pressure; assure correct sizes have been used.
- Replace compressor driving belts annually; maintain all other critical parts as needed.
- Ensure that water cooling ducts are not blocked.
- Regularly maintain air-operated equipment as well as "conditioning units" — filters, pressure regulators, and lubricators.
- Do not operate equipment above manufacturer's recommended operating pressure.
- Provide basic instrumentation to gauge system efficiency.

Electrical systems

Electrical systems are often ignored when energy requirements are assessed. Poor maintenance is a large contributor to high operating costs. Improper use of electrical systems can not only consume excess energy, but create fire hazards and danger to the safety of the personnel. Motors operating at lower-than-designed voltages will use more amperage than intended. Wires too small for the load create line losses and risk of fire or shock. Transformers should be checked regularly for leaking oil, dirt, and proper ventilation. All contacts should be inspected for shorting — the signs are burned spots or frayed wires. An electrical load analysis should take place at the beginning of the program, as well as periodic preventative maintenance.

Electrical System Management

- Inspect equipment for frayed or burned wire semiannually.
- Perform electrical load analysis when major equipment changes occur, or every 2 years.
- Calibrate thermostats annually.
- For transformers, inspect gauges and remove debris monthly; sample and test dielectric annually; remove cover and check for water every 10 years.
- Perform survey semiannually for lighting in actual use.

Equipment

Although manufacturing equipment is unique to each facility, most plants have many devices in common that require similar maintenance. With fans and pumps, motors are frequently oversized for low temperature or full load startups. Fan horsepower requirements can be saved by preheating air during cold weather or assisting startup with an inlet vortex damper. Improper mounting of motors is another energy consumer. Bearings must be properly maintained to avoid costly failures, and lubricant levels, alignment and vibration should be checked on a regular basis. Ovens are large energy users, and must be watched for refractory or insulation failure and leaky seals and gaskets. Thermostats and other instruments should be calibrated regularly.

Process Equipment Energy Maintenance

- Chillers — annually inspect electrical connections and valves and bearings, clean condenser and oil cooler.
- Compressors — each month check oil levels, inspect for leaks, log oil temperature and pressure; each year remove rust, replace drive belts, check wiring.
- Control tubing — examine monthly for leaks.
- Cooling towers — inspect daily for clogging; check gear reducer oil level weekly, for sludge and water monthly; semiannually inspect for leakage and tighten loose bolts; each week clean suction screen.
- Fans — each month check fan belts for tension and wear; twice a year check fan blades and clean, check pulleys for wear and alignment, check for drive noise, vibration.
- Motors — twice a year check alignment and mountings; lubricate bearings when needed.
- Ovens — check insulation, controls, firebrick semiannually.
- Piping — check mountings each year; inspect for leaks semiannually.
- Pumps — examine lubrication monthly; look for leaks twice a year.

New techniques

Recent technological developments are on the market to aid energy conservation. Examples include:

- Decal temperature indicators that give on-the-spot visual evidence of heat at the outlet of a steam trap.
- Large axial ceiling fans move plant air slowly for ventilating, and bring warm air down from the ceilings for worker comfort.
- Tanks of hot liquids are insulated with a layer of light floating balls, preventing the escape of heat.
- The development of microprocessors gives the capability of controlling loads and equipment operation continually and with low manpower requirements.
- Gas-fired infra-red heaters heat only objects that absorb radiant heat, such as human bodies, but do not heat the surrounding air.
- Turbulators create turbulence in boilers after the heated gas leaves the burner, increasing heat-transfer efficiency.

This article is a general survey of maintenance techniques to help conserve energy in process plants. There are numerous publications available giving details for such programs. Two helpful works the reader may refer to are: The Enersave Series of Industrial Energy Conservation Manuals, Ministry of Energy, Mines and Resources, Ottawa, 1977, and Energy Management Handbook, edited by Wayne Turner, John Wiley & Sons, Toronto, 1982.

Energy Management Instruments

System	**Instrument**	**Variable examined**
Building envelope	Infrared photography	Heat loss
Boilers	Bourdon gauge, diaphragm gauge, manometer	Air, fuel pressures
	Orsat apparatus	Stack-gas analysis
	Mounted meters	
	Smoke detector	Smoke
	Thermometers	Temperature
	Chart recorders	Steam demand
Steam traps	Thermometer (sensitive)	Temperature differences between inlet and outlet
	Stethoscope	Opening and closing noise
Heating, ventilating, and air conditioning	Flow hood	Air flow rates
	Pitot tube	Air flow rates
	Inclined-tube manometer	Pressure differential between two points
	Bourdon tube	Pressure
	Pocket thermometer	Temperature of rooms, pipes, etc.
	Orifice flowmeters	Flow rates of air or steam
	Psychrometer	Humidity
Electrical	Ammeter, recording	Electricity usage, peaks
	Ammeter, clip-on, with probes	Voltage, current, resistance
	Wattmeter, recording	Power consumption
	Power-factor meter	Electrical power factor
Lighting	Industrial lightmeter	Light levels
Hot water	Thermometer	Temperature
Air compressors	Pressure gauges	Oil pressure, air pressure
	Stethoscope with gauge	Bearing wear on motors
	Multimeters	Voltage balance on three-phase motors
	Strobe light	Motor vibration
	Infrared film and camera	Bearing wear

Non-Contact

Digital Infrared Thermometer

Specifically Designed For Industrial Process Control And Plant Maintenance

STANDARD FEATURES

- One model measures broad temperature range: From −20°to +2000°F (−29° to +1093°C)
- Push button to select °F or °C readout
- Peak-hold control
- Digital emissivity control
- Single 9-volt long-life battery power
- 8-14 micron spectral filter eliminates effect of ambient light, water vapor, and CO_2 absorption
- Automatic ambient temperature compensation
- Sensitivity: 1°F/1°C
- One second response for rapid scanning
- High resolution field of view
- No drift with temperature and time

STANDARD CONTROLS

- Off/on trigger: two operating positions (second position for peak hold)
- Push button selects either °F or °C
- Digital emissivity

HOW TherMonitor™ WORKS

All objects emit infrared (heat) radiation as a well-defined function of their temperature. The TherMonitor™ collects and focuses this radiation onto an infrared detector which converts it to an electrical signal. That signal is then amplified, linearized, and displayed on a digital meter in °F or °C. The auto-zero circuit and internal ambient reference eliminate drift with temperature and time.

DESCRIPTION

The TherMonitor™ is a portable, battery-powered, digital Infrared thermometer designed to measure surface temperatures without contact. The basic components of this instrument consist of a protective window, collecting optics, spectral filter, infrared sensor, low noise amplifier, ambient temperature reference, linearizing network, liquid crystal display, and battery power source.

APPENDIX F.3.

Three Systems of Load Management

Note - There are many other load management systems on the market. The systems shown are to illustrate the type of equipment available and their appearance here does not imply an endorsement.

1. Allen-Bradley Energy Management Systems
   Allen-Bradley Canada Ltd.,
   Cambridge, Ontario

2. The Honeywell Load Management System
   Honeywell Ltd.,
   Toronto, Ontario

3. The PSC Demand Control and Auto-Correction Systems
   P.S.C. Controls Ltd.,
   Laval, Quebec

ALLEN-BRADLEY ENERGY MANAGEMENT SYSTEMS

The Allen-Bradley Energy Management Systems (EMS) are based on the principle of comparing a reference demand rate against the actual demand. The two major methods of establishing a reference demand are referred to as ideal rate and forecasting.

IDEAL RATE METHOD – The ideal rate technique operates on the principle that if an ideal rate of energy usage is generated and compared to the actual rate of energy usage, as shown in Figure 3, the difference between them can be used to shed and restore loads so as not to exceed a selected maximum demand.

An initial offset is applied so that unnecessary control action will not take place early in the demand interval.

The ideal energy rate, offset, shed and restore points are presettable which allows the flexibility of changing the operation as requirements are changed. The actual rate of power used is continuously compared with the ideal rate. As the two curves approach each other, the difference readout will become smaller, and when it reaches a point (for example Ⓐ) loads under that priority level will be removed. Similarly, if the actual rate of power being used decreases and the difference readout becomes larger, the same loads will be restored under that priority level at a preset difference (for example point Ⓑ).

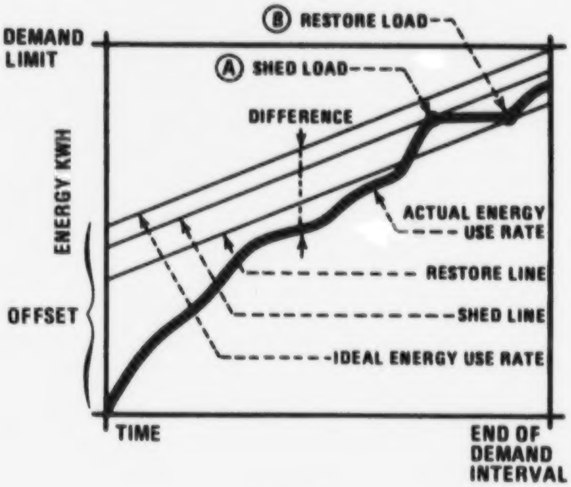


Figure 3

ALLEN-BRADLEY ENERGY MANAGEMENT SYSTEMS

FORECASTING METHOD – The forecasting method typically utilizes historical data to project what the future demand will be.

As illustrated in Figure 4, the EMS will determine, at selected points in time, whether or not control action is required according to a pre-established calculation. Whenever the calculation predicts that the total energy consumed will exceed the demand limit (forecast over) unless control action is taken, the EMS begins shedding loads as required and restoring loads as possible.

If the calculation indicates that the total energy consumed in the demand or sample interval will not exceed the demand limit (forecast under), the EMS will take no further action until the forecast calculation is performed again.

It is possible that other control interlocks may override a given control action. For example, it is possible to configure an EMS so that a particular load would not be shed (timer override) when the control action calculation determined that the total energy consumed in a demand interval would exceed a demand limit. These overrides are important when controlling time dependent loads like compressors (prevent short cycling) and water heaters (prevent excessive shed times).

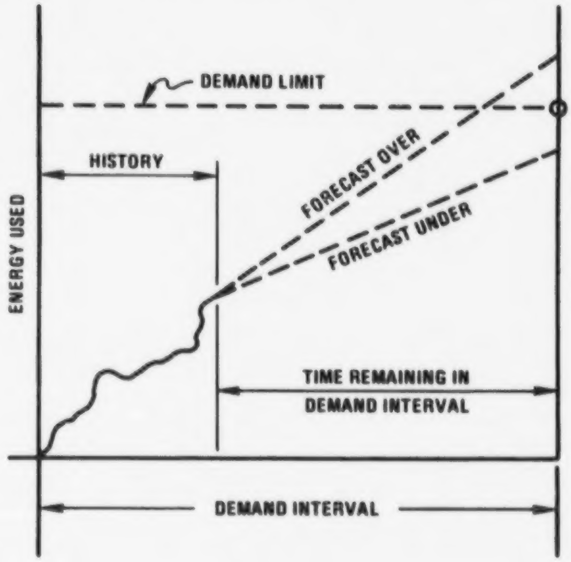


Figure 4

The Honeywell W7000 System: the answer to spiraling energy costs. Energy. There is no way your business can do without it. Yet, spiraling energy costs are making utility bills a major factor in every month's P&L statement.

Some managers believe that there really isn't any practical, cost-effective way to manage and reduce energy costs. But, there is: the Honeywell W7000 Microprocessor Based Load Control System. Honeywell's W7000 System brings your energy usage under control and substantially reduces your energy costs. It pays for itself rapidly, usually within 2 to 3 years and keeps on saving. For example, the W7000 System can be used to control:

- ☐ Air conditioning units and exhaust fans
- ☐ Interior & exterior lighting
- ☐ Compressors and other refrigeration equipment
- ☐ Electric heating equipment
- ☐ Electric water heaters
- ☐ Disposals & compactors

The W7000 System. The W7000 Microprocessor Based Load Control System is compact and versatile. It can be applied to restaurants, office buildings, supermarkets, convenience stores, drug stores, hotels/motels and many other commercial buildings. Any or all of the three money-saving system methods previously described could be applied to any application.

All models include a unique combination of capabilities: the W7000 System can control up to 10 or 20 loads or groups of loads.

Light emitting diodes (LED's) display the program status and also tell you which devices are OFF or ON.

System programming is required only once.

The W7000 System has been designed to minimize unauthorized tampering; it allows you to select a unique program access code.

In addition, the system contains self diagnostics that detect and trouble-shoot problems automatically. It also protects itself and its program from power interruptions with a built-in battery back-up system.

Programming the W7000 System is easy. A human factor engineered prompting method, where the LED display asks (in English) for your entry and you respond by entering your program on a keyboard, has made programming truly simple. Included with each model is an easy-to-understand operations manual. This manual was carefully designed to enable programming of the W7000 System without special training or previous programming knowledge. If you should happen to make a mistake, the system displays an error message that will tell you just what type of mistake you have made.

The Time-of-Day Programmer can be programmed to control loads for all seven days of the week identically or differently. There is an additional program day for holidays which can be programmed for years in advance. An annual clock provides indication of the YEAR, MONTH, DAY-OF-MONTH and TIME on an LED display and even remembers to adjust for standard and daylight savings time and leap years. There is also a program bypass key which allows you to over-ride the time-of-day programmed loads from 0 to 90 minutes.

The Demand Limit Controller includes a digital display which indicates present kw demand and active demand limit set-point. It provides you with the choice of using an instantaneous or an average kw demand signal. Two kw set-points are programmable and either may be automatically activated by a simple switch closure. The Demand Limit Controller has an alarm light which indicates that kw demand is exceeding the set-point after all eligible loads have been shed. For each load controlled by the Demand Limit Controller, you can program MAXIMUM SHED, MINIMUM SHED, and MINIMUM ON times to optimize your savings.

With the Demand Limit Controller you also receive a built-in energy auditor. The peak kw, time of the peak and kilowatt hours of consumption for a 30-day period are automatically stored in memory and can be displayed at the touch of a button.

The Duty Cycler reduces kwh consumption by cycling loads according to a program based upon outside air temperature. It allows you to program up to three separate temperature-dependent duty cycle programs for each channel. The Duty Cycler uses a solid state outdoor temperature sensor to determine the correct duty cycle for each load. Outdoor air temperature is indicated by a digital display.

Options currently available for your W7000 System include:
(a) Manual bypass switches, and
(b) Communications module.
These install directly into the W7000 System.

The Manual bypass switches allow you to bypass the operation of each W7000 System load channel individually, to simplify checkout and maintenance.

The Q7000 Communications Module may be field-added to any system installation and provides the following functions over standard dial-up telephone lines:

- ☐ Building address, W7000 model installed and current time.
- ☐ Remote programming.
- ☐ Recall of programs.
- ☐ Check for malfunctions.
- ☐ Determine which loads are OFF or ON at any given moment.
- ☐ Detailed energy audits (only on models with control) which include peak, time of peak, kilowatt hours and the maximum, minimum and average outdoor air temperature for each day and the last 30 days.

P.S.C.
4800-7000-8000

DEMAND CONTROL SYSTEMS

General

Energy is the topic of the day. PSC, since its incorporation, has been totally involved in the efficient application and control of electrical energy. Our Marketing and R & D staff, in continuous consultation with major electrical utilities, has developed many successful products with original control concepts.

PSC pioneered in the development of such features as Automatic Demand Control and Automatic Temperature Demand Setting, whereby seasonal control is automatically optimized between billing and the requirements of an acceptable environment. The wide range of available features enables us to supply systems which once installed require no attention for seasonal or operational readjustments.

At present, the company designs and manufactures products ranging from a small Electrical Entrance Protection circuit for residential application, to large computerized Total Energy Management Systems for commercial and industrial installations.

Forecasts for energy cost inflation of 20% per year justify total or partial automation in most existing and new buildings. Our management consulting group will be pleased to assist you in evaluating your energy position and in establishing the building supervision and control requirements.

Systems description

PSC Demand Control Systems cover a wide range of applications and therefore are divided into three groups of systems reflecting different packaging style, cost range and flexibility.

PSC 4800 is the simplest of the systems offering only basic functions for applications in power demand control, power factor correction or temperature stabilization.

PSC 7000 has added flexibility in metering selection, load control and sequential switching programming.

PSC 8000 is a computer based system offering not only a highly sophisticated Demand Control System but also the capability of configuration as a Total Energy Management and Building Management System. A separate write-up is available on 8000 series systems.

Operation

The function of the demand controller is to measure at building electrical entrance the kW component of the power and then to provide switching control for the electrical loads. The measured power is integrated and compared to set demand level and the loads are sequentially disconnected when the monitored power is above set level. Conversely, the loads are sequentially reconnected when integrated power is below set differential level.

The numerous metering and controlling schemes allow the structure of the operation to meet both simple and complex requirements.

P.S.C. 6000
POWER FACTOR AUTO-CORRECTION SYSTEMS

General

Electrical utilities are increasingly imposing penalties for inefficient power factor. In many factories, food stores, and air conditioned buildings, the penalty may reach 5 to 45% of the total electrical cost. This situation can be corrected with payback on investment of less than two years.

Traditionally, as corrective measure, capacitors are being connected across motor power supply, or in a group as bank installation at some central point such as main plant bus. The first approach does not take advantage of the diversity in the equipment operation and therefore is expensive. The second approach lacks a control to maintain system stability under varying load condition.

The PSC-6000 system continuously monitors overall building power factor and switches at the main electrical entrance or main feeder an appropriate reactive compensation from the central bank of capacitors.

This approach has several advantages:

- The diversity of the equipment allows you to connect a smaller load of capacitors.
- Costs are reduced by the use of a central group of capacitors instead of many individual capacitors throughout the building.
- The modular approach enables expansion of electrical load.
- Correction of power factor permits further addition of useful electrical loads.
- Improves the efficiency of motors and lighting by providing higher, more uniform voltage levels.
- Decreases current and transformers losses.
- Reduces electrical energy cost.

The PSC-6000 can be supplied as a completely assembled and prewired cabinet, including: power factor monitoring unit, bank of capacitors, fuses, contactors and other required optional accessories. The only on site requirement is the connection of the PSC-6000 system to the main service entrance.

Features

- **Field proven design.**
- **Display and indicators confirm operating status of the system and control circuits.**
- **Test features provide thorough check and location of faulty circuit.**
- **Alarm set independently continuously monitors inadequacy of the system.**
- **By-pass switches enable manual operation.**
- **Differential level adjustment enables field selection of the operating parameters.**
- **Solid state control establishes well balanced system response time.**
- **Safety features incorporated in both mechanical and electrical design.**
- **Modular construction enables easy field expansion.**
- **Layed-out for ease of installation and maintenance.**
- **Compact arrangement saves space.**
- **Factory wired to reduce installation cost.**
- **Short delivery of standard models.**
- **Consulting services available.**
- **Turn-key job contracts offered.**

APPENDIX F.4.

Portions of

ENERGY EFFICIENT MOTORS

Energy Conservation and Utilization Division
Ontario Hydro
620 University Avenue
Toronto, Ontario
M5G 1X6

Advantages of `Energy Efficient´ Motors

Reduction of operating costs is the significant advantage of using an "energy efficient" motor, but the benefits do not stop there.

Since the motor is more efficient, it generates less internal heat and runs cooler. This will contribute to longer life. Reduced heat may also contribute to savings through reduced air conditioning. Or an "energy efficient" motor used in a refrigeration system not only performs work more efficiently but also contributes less heat to the system, reducing the work to be done!

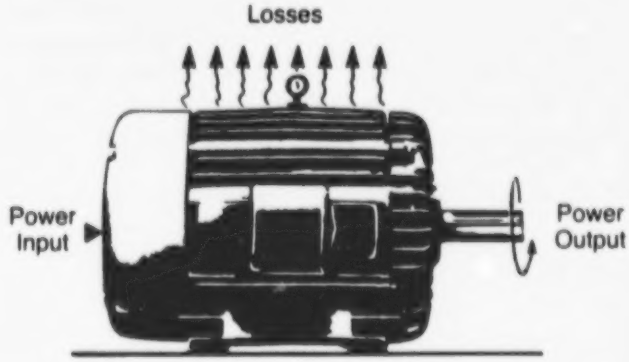
"Energy efficient" motors also have an improved power factor. This can have a number of advantages:

- reduction or elimination of power factor penalties
- less loading on feeder circuits and transformers
- reduction or elimination of capacitors used for power factor correction.

Also, because of the extra material in the "energy efficient" motor, it's power factor and efficiency are less sensitive to voltage and loading fluctuations.

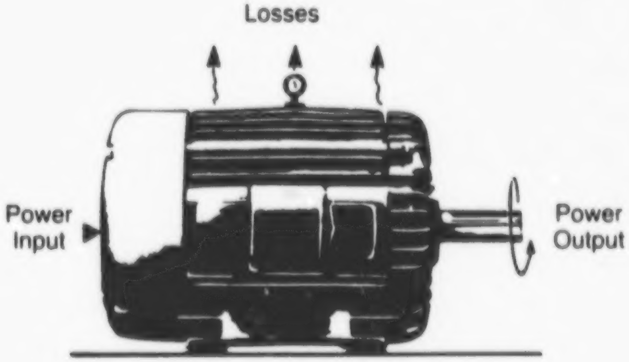
Motor Losses—
What Makes an 'Energy Efficient' Motor?

The efficiency of an electric motor is defined as $\frac{\text{OUTPUT}}{\text{INPUT}}$



The power input to the motor is either transferred to the shaft as power output or is lost as heat through the body of the motor.

"Energy efficient" motors have reduced losses and so require less electrical power input, while still providing the same mechanical power output.



But at what point does a motor become "energy efficient"? Certainly the electric motor, in general, is a relatively efficient device. On this basis some motor manufacturers will claim their standard motor is "energy efficient", but this is questionable. Most "standard" motors are designed to provide good service at a competitive price, while meeting all performance requirements. "Energy efficient" motors offered by some manufacturers have been designed to provide the highest efficiency practical, at a somewhat higher price.

Figure 5.1 shows typical efficiency improvements that are possible by using an "energy efficient" or "high efficiency" motor.

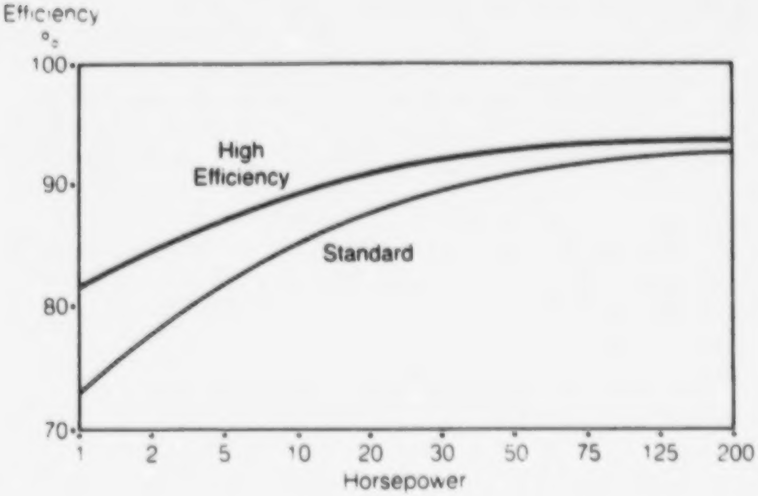


Figure 5.1
Motor Efficiency Comparison

This improvement in efficiency is basically accomplished by:

- using more material in the motor
- using better material
- design changes

Even though the percentage improvement in efficiency grows smaller in the higher hp ranges, the actual watts reduction increases as the horsepower increases (see Figure 5.2). Therefore, the full 1-200 hp range deserves attention.

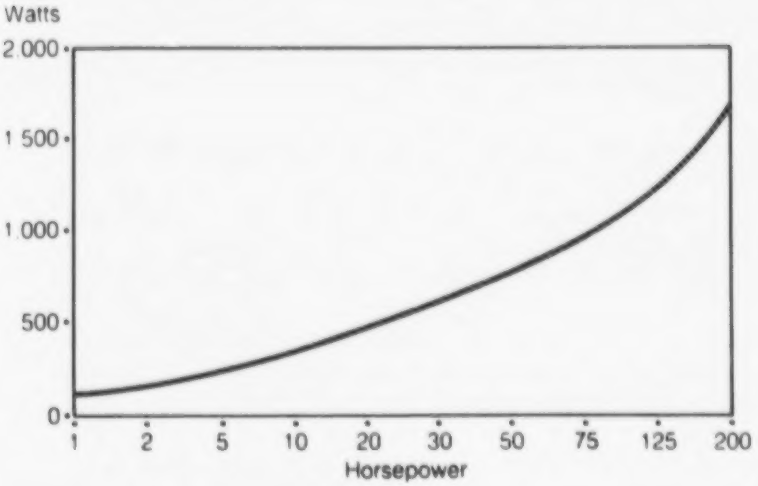


Figure 5.2
Typical Loss Reduction with High Efficiency Motors

Efficiency Standards

To begin, we should appreciate that different motors of the same design will not necessarily have the exact same efficiency. Manufacturing tolerances, variations in raw materials, etc., will cause some discrepancies. Consequently, different efficiency terms have been developed.

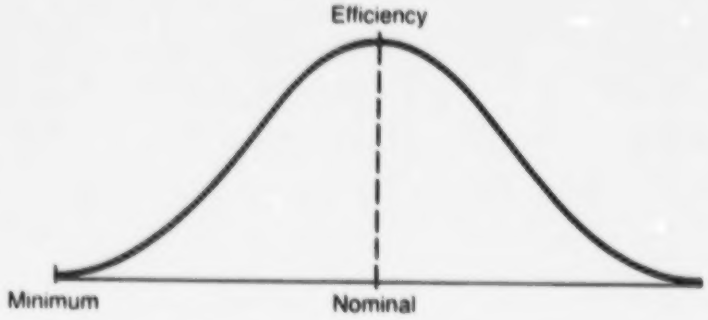


Figure 8.1
Efficiency Bell Curve

"Average expected" or "Nominal"	- a large population of motors will have this efficiency as an average value.
"Guaranteed" or "Minimum"	- all motors should meet or exceed this value.

Unfortunately there is still some leeway in the interpretation of these terms. For example, some motor manufacturers may claim that a "high percentage" (not all) of their motors meet the minimum efficiency level. The important aspect here is to recognize the different terms and make sure you compare like terms. For example, it would be inaccurate to compare one motor's "nominal" efficiency with another motor's "guaranteed" efficiency.

Also, don't be misled by the term "apparent efficiency". "Apparent efficiency" equals efficiency times power factor. It is a term used as an indicator of a motor's overall efficiency and power factor but does not tell you the specific value of either one! Motor selection should not be based on "apparent efficiency". Rather, efficiency and power factor should be specified separately.

This whole matter of efficiency is further complicated by the fact that there are different methods of measuring efficiency. The same motor tested to different efficiency standards can produce a variety of different efficiency values.

The main problem is the manner in which the elusive "stray load losses" are dealt with. European standards assume a fixed percentage for them, Japanese standards ignore them and the American IEEE 112A standard offers both an indirect method of calculating stray load loss (used in method B) and a rigorous method of measuring them directly.

IEEE 112A (method B) is currently regarded as the most accurate standard for motors in the 1 to 200 hp range and is the recommended standard to use in efficiency comparison. It is, however, still rather vague and hard to follow, leaving room for misinterpretation. The Canadian Standards Association (CSA) is currently developing an improved efficiency test standard based on the IEEE method. It will provide motor manufacturers with a definitive technique for determining efficiency and will take the guesswork out of efficiency comparison for the motor purchaser. Look for it and use it in your motor purchasing specifications in the near future.

Finally, remember again that you can not compare "apples with oranges". Make sure you're comparing the same type of efficiency (eg. nominal as opposed to minimum) and that the efficiencies have been determined by a common test method.

Motor Loading

How much of a "safety margin" should be used when determining the horsepower required for a job?

Certainly there are a number of valid reasons for "over-sizing" motors:

- insurance against motor failure in critical processes
- ability to increase production
- load fluctuation
- "wear and tear" increases effective load

Unfortunately, excessive 'fudge factors' are often used in the load calculations resulting in the selection of a motor that is grossly over sized (or under loaded) for the job. How does this affect the motor's performance?

Shown in Figure 9.1 is a graph of efficiency and power factor for a typical induction motor. While efficiency is not seriously affected, power factor suffers greatly at reduced load operation.

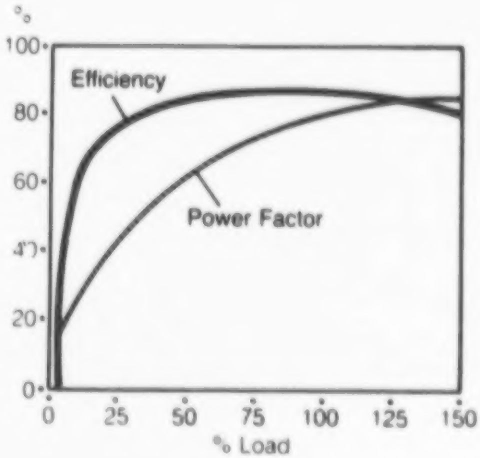


Figure 9.1
Efficiency & Power Factor of
Typical Three Phase Motor

(Peak motor efficiency actually occurs at about 75% to 80% load).

As an example, suppose you had to drive a 75 hp load. What would be the kW, KVAR and kV·A requirements using larger motors than necessary?

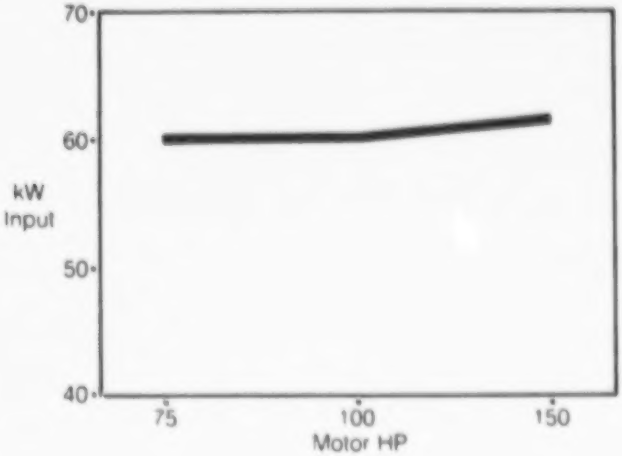


Figure 9.2
75 HP LOAD

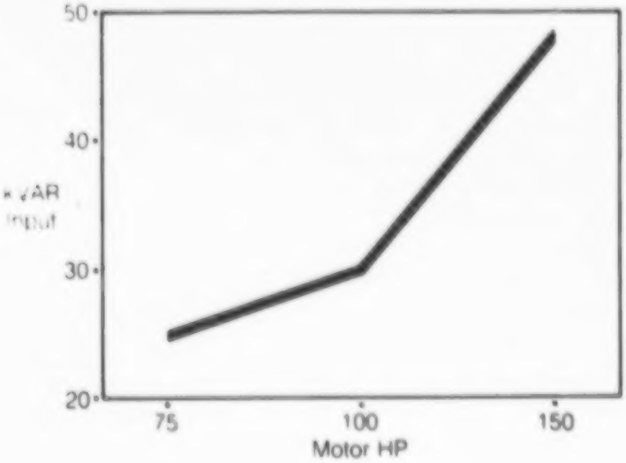


Figure 9.3
75 HP LOAD

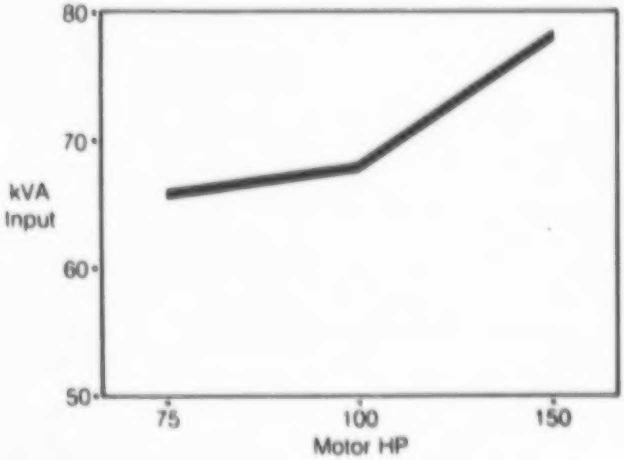


Figure 9.4
75 HP LOAD

The kW required is approximately the same regardless of the size of motor used. The KVAR required, however, climbs rapidly as a larger motor than necessary is used. As a result, the kV·A required, which determines the size of switchgear and electrical cables used, will also increase.

The cost of using a larger motor than necessary quickly adds up:

- increased motor purchase cost
- increased cost of electrical supply equipment
- power factor penalties
- increased energy costs (where severe over-sizing occurs)

A reasonable over-sizing margin is to operate the motor between 75% and 100% load. This is usually accomplished simply by recognizing that induction motors are only available in so many sizes. For example, if calculations show a load requirement of 35 hp, a 40 hp motor will have to be used, operating at 88% load. When a motor is used for a non-critical constant load application, such as on a fan, it should be sized as close as possible to 100% load.

Remember that when a motor has a service factor greater than 1.0, it has been designed to operate satisfactorily at the service factor load (eg. sf = 1.15 can operate at 115% load continuously), although at a slightly reduced efficiency. Short term overloads can often be accommodated by this service factor capability rather than by using a larger horsepower motor.

Motor Maintenance

The squirrel-cage induction motor is a rugged device and, when properly applied, will provide years of service with a minimum of maintenance. There is no question, however, that simple regular maintenance and inspection will provide greater longevity. A record of maintenance history can provide information about when and why motors fail.

Be aware of changes in a motor's usual performance. For example:

- is the motor noisier than usual?
- is the motor frame temperature higher than normal?
- does the motor take longer to come up to speed?
- is there an increase in vibration?

When properly interpreted these symptoms can help to avert serious trouble or motor failure.

Dirt

If screens or filters become clogged air flow will be reduced and the motor could overheat, eventually leading to insulation failure. Keep the motor clean by wiping with lint-free rags, using suction to draw out dust or clean using compressed air, being careful not to drive dirt further into the machine.

Moisture

Motors that are used continuously are not prone to moisture problems. It is the intermittent use or standby motor that may have difficulties. Try to run the motor for at least a few hours each week to drive off moisture. Be careful that steam and water are not directed into open drip-proof motors. Where totally enclosed motors are used in a humid environment remove any condensed water through the drain plug and, if possible, leave the drain plug out.

As a check, "megger" the windings to check the condition of the insulation. The reading for 575 V motors at 25°C should be 1 megohm or greater. If it is not, the windings may require drying.

Greasing

Over-greasing of anti-friction bearings increases friction, causing the bearing to overheat. This is the most common cause of bearing failure. Rather than packing the bearing full of grease until it runs out the plug hole, the bearing should be filled not more than 30%. Then it is still a good idea to leave the drain plug out while the motor runs for about ten minutes, allowing any excess grease to escape.

Be sure not to use contaminated or improper lubricants, as this is another cause of bearing failure.

Vibration

A noticeable increase in motor vibration is an indication of trouble. If it occurs:

- check that all mounting bolts are tight
- check shaft for proper alignment
- bearings may be at the end of their useful life.

Identifying the source of vibration can sometimes be a difficult problem. Often the motor manufacturer can assist you in measuring and analyzing vibration problems, particularly with large motors.

Starting

Excessive starting is a prime cause of motor failures. The high current flow during start-up contributes a great amount of heat to the motor. For motors 200 hp and below, the maximum acceleration time a motor connected to a high inertia load can tolerate is about 20 seconds. The motor should not exceed more than about 150 "start-seconds" per day.

Even with low inertia loads that come up to speed in a fraction of a second, the mechanical stress caused by frequent starting can lead to a premature motor failure, even if the total "start-seconds" remain low. Where starting requirements are severe, and with motors 250 hp and above, starting requirements should be discussed with the motor manufacturer prior to purchase.

APPENDIX G.1.

Articles mainly dealing with procedural methods of achieving energy efficiency in injection molding.

1. Energy Considerations in Planning an Injection Molding Operation
   Rodolfo Selem   Systems Engineer
   Husky Injection Molding Systems Ltd.,
   Bolton, Ontario
   Reproduced from Modern Plastics
   September 1982

2. Energy Efficiency in Injection Molding
   Robert E. Nunn and Kenneth Ackerman
   HPM Corporation
   Mount Gilead, Ohio
   Presented at Society of Plastics Engineers Technical Conference
   May 1981

3. Possibilities Whereby the Machine Setter Can Influence the Energy Consumption of the Injection Molding Process
   Dipl.-Ing Helmut Eckardt
   Battenfeld Maschinenfabriken Gmbh
   Meinerzhagen
   Federal Republic of Germany

Energy considerations in planning an injection molding operation

By Rodolfo Selem*

Determination of the energy requirements of each individual injection-machine function allows a molder to calculate accurately the total energy cost for any part to be produced. Knowledge of the impact of mold and machine designs on relative energy consumption is also useful in evaluating equipment

Energy efficiency has become a household phrase in industry today. The cost and availability of energy are important factors in planning any manufacturing enterprise. Injection molding is no exception.

Over the past few years, mold and machine manufacturers have improved basic process technology through R&D programs that have upgraded the energy efficiency of everything: from pumps, motors, heaters and valves to clamp and injection units. Molders have been inundated with promotional literature in which manufacturers make claims about the energy efficiency of their equipment. However, most of these claims define an energy-efficient piece of equipment as one requiring a low connected load. Virtually no one relates power requirements to equipment throughput rates—*i.e.*, what power is needed vs. what the machine can produce.

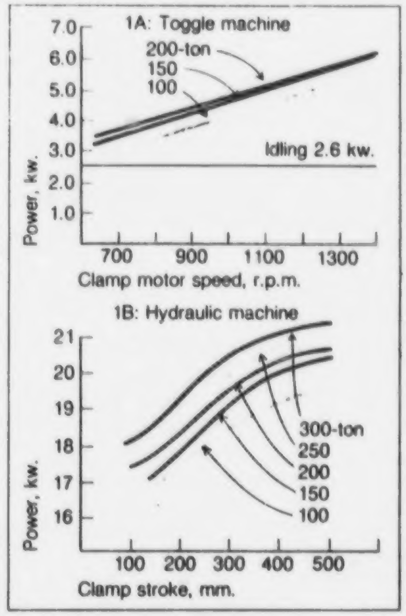


Fig. 1: Energy consumption by toggle and hydraulic clamps vs. stroke and tonnage.

Three years ago we began our own analysis of energy efficiency in injection molding operations. From our initial measurements with a portable energy monitor built by Materials Control, Inc. (Matco), N. Aurora, IL, we concluded that out of all the electrically powered equipment in a typical injection molding plant, the injection machine itself consumes the greatest amount of energy—up to 65% of all electricity consumed in the entire plant (Table I). Concentrating on improving the energy efficiency of the injection molding machine, therefore, will have the greatest impact on reducing overall plant power consumption.

We realize that the only practical and logical way of measuring energy efficiency is by relating electrical *input* to product *output* in pounds per hour. In other words, how many kilowatt-hours are required to produce "X" pounds of finished product (energy efficiency = kw.-hr./lb.)? Furthermore, our tests showed that there is no evidence of any correlation between connected load and energy efficiency measured in terms of kw.-hr./lb. Energy efficiency depends on several variables, such as machine tonnage, mold design, and cycle speed. We concluded that in comparing different machines for efficiency, comparisons should at least be made on machines running the same mold and producing the same parts.

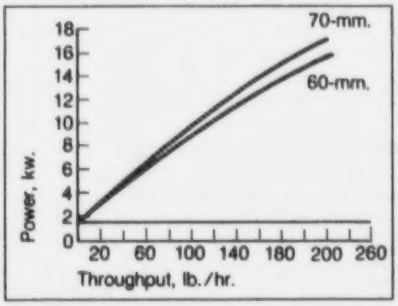


Fig. 2: Energy consumed by extruder drive for general-purpose PS vs. throughput and screw diameter.

To estimate the total energy consumption of an injection molding machine, the energy requirements of each individual machine function were measured. Once these demands were known, it was possible to obtain the total energy consumption by adding up the individual requirements. The output of a mold is a known factor supplied to molders by mold manufacturers. Therefore, determining energy efficiency—*i.e.* total energy consumption per pound of throughput—can be accurately estimated by simple arithmetic.

Test equipment and procedure

The equipment selected to measure electrical requirements (kw.) was a digital clamp-on power tester and an integrator unit designed to display power consumption over a period of time.

The equipment costing $4,100 and manufactured by Hioki N.Y. Corp., Douglaston, NY) offered several advantages over the unit used in the preliminary tests: 1) The new equipment could easily be connected to any circuit in the molding machine without interrupting machine operation. 2) It provided automatic power-factor calculations, thereby eliminating secondary steps. 3) It was

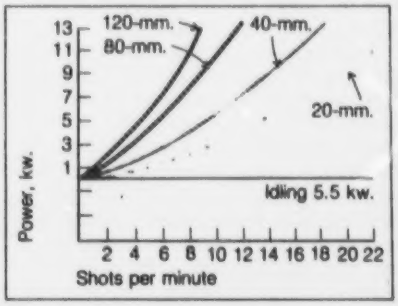


Fig. 3: Energy consumed by injection unit vs. shots/min. and injection stroke.

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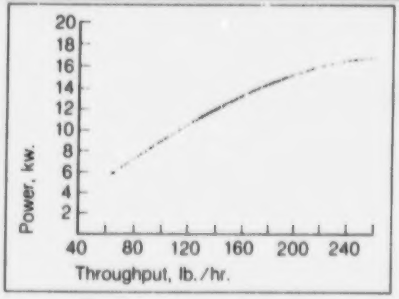

Fig. 4: Energy consumed by heaters vs. polystyrene throughput (based only on thin-wall moldings).

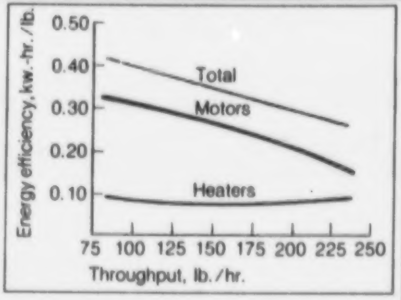

Fig. 5: Relative energy efficiency vs. throughput. Material: LDPE. Mold: four-cavity, 32-oz. container (37.6 g.), hot-runner. Machine: hydraulic-clamp.

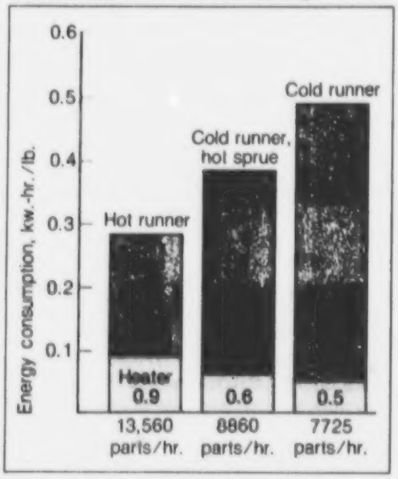

Fig. 6: Energy consumption vs. runner-system design.

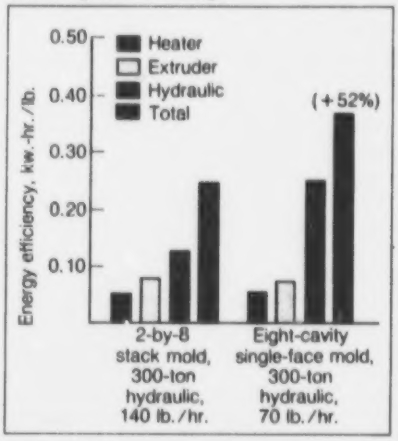

Fig. 7: Relative energy efficiency of stack molds vs. single-face molds (11-g. PS audio-tape cassette-box base).

more accurate, reliable, and portable.

Molders who want to use our approach need not purchase such sophisticated monitoring equipment. Several suitable power testers are available at lower cost.

A 200-ton toggle-clamp two-stage injection molding machine was the primary unit used in our investigations. A 300-ton two-stage hydraulic-clamp machine was also analyzed for hydraulic-clamp performance. Both machines were run under normal production conditions, using g.-p. polystyrene.

The measuring device was connected to the power-supply circuit of each machine function that consumes energy; the clamp, extrusion, injection, and heater functions were analyzed individually. Motor idling for each function, excluding heaters, was also factored in. Each function was measured against key variables that affect energy consumption. The toggle clamp was measured against tonnage and clamp-motor speed; the hydraulic clamp was measured against tonnage and stroke; the extruder was measured against throughput and screw size; the injection unit was measured against stroke and machine cycles; and heaters were measured against throughput and material.

Variables were changed for each function to simulate different molding conditions. Readings were gathered at each different setpoint and graphs were plotted reflecting how energy consumption changed in relation to changes in the variables. Finished graphs illustrated what the energy consumption was at specific points for each function. What's more, the graphs showed precisely which variables had the most influence on energy consumption and implied which variables could be changed to obtain optimum energy efficiency.

Energy consumption

Toggle clamp (Fig. 1A): Clamp-motor speed had a greater impact on energy consumption than did tonnage. More energy was used as speed increased. Tonnage had only a marginal effect.

Hydraulic clamp (Fig. 1B): Since the hydraulic clamp is tied into the main hydraulic pump motor, all other functions were disconnected except the clamp, and the machine was dry cycled. Again, tonnage differences played only a minimal role. Clamp stroke consumed more energy as the distance of moving-platen travel was increased.

Extruder (Fig. 2): Material used played an important role in measuring energy consumption of the extruder drive; a different graph would have to be generated for each material used. For our analysis, general-purpose PS was used. Although a larger-diameter screw consumed somewhat more electricity, energy consumption was found to be more dependent on throughput.

Injection (Fig. 3): As length of stroke increased, energy consumption increased to some degree. However, machine cycles (shots/min.) had the greatest impact on energy consumption. Measurements taken on the injection speed revealed only a marginal effect on overall energy requirements of the injection unit.

Heaters (Fig. 4): All mold and machine heaters were analyzed. Increased throughput had the greatest effect on energy consumption. It should be pointed out that extruder screw design has a direct influence on heater requirements, since the screw imparts the most heat-transfer energy to the material.

Case study

What follows is a practical example of how the data presented can be used to predict energy requirements.

Assume a 9-oz. PS cup weighing 12 g. is to be manufactured. The mold manufacturer says an eight-cavity hot-runner mold operating at 15 shots/min. should be used. Therefore, the plasticating rate is calculated at 190 lb./hr.

The machine supplier suggests using a toggle-clamp two-stage injection machine. Clamp force is 200 tons, speed is 1200 r.p.m., injection stroke is 40 mm., and extruder screw diameter is 70 mm.

Using curves we find that the clamp will consume 6 kw., the extruder drive 15.5 kw., the injection unit 10.0 kw., and the heaters 15.5 kw. to produce the cup. Total load is 46.5 kw.

From these figures we can calculate the energy use:

Energy use = Consumption (kw.) = 46.5 kw.
Throughput (lb./hr.) = 190 lb./hr.
= 0.245 kw.-hr./lb.

Furthermore, energy costs for manufacturing the cup can also be calculated. Assuming that 1) production hr. required = 5400 hr. (typical yearly availability) and that 2) energy cost = $0.05/kw.-hr.:

Yearly energy use = 5400 hr./yr. x 190 lb. x 0.245 kw.-hr./lb.
= 251,400 kw.-hr.

(Continued on p. 86)

Table I: Calculation of substation requirements for operating 10 injection molding machines

Plant equipment	Maximum expected demand, kva
Injection molding machines	950[a]
Raw-material handling	11
Chillers	80
Cooling tower	30
Air compressors	52
Plant lighting	60
Ventilation	3
Air conditioning	96
Mold maintenance	50
Machine maintenance	50
Secondary operations	25
Offices	50
Total	**1457**

[a]: 65% of total kilovolt-amperes (kva).

Total energy cost/year = \$0.05/kw.-hr. x 251,400 kw.-hr./yr.
= \$12,570/yr.

We believe that predicting energy requirements by analyzing power consumed by each machine function and relating it to throughput is a practical approach. Moreover, a detailed analysis of the curves generated in our tests implies that energy efficiency improves as throughput increases. (Fig. 5). Therefore, molders should examine innovative approaches to mold and machine component designs that provide higher output if increased energy efficiency is included among their goals.

For example, runner design can play an important role in increasing output. Fig. 6 shows the results of tests run on three different runner designs producing similar parts. A hot-runner mold provided energy consumption of 0.25 kw.-hr./lb.; a cold-runner/hot-sprue mold results in 0.36 kw.-hr./lb.; and energy consumption of a cold-runner mold was 0.5 kw.-hr./lb., *i.e.*, 100% more energy was expended to manufacture 58% fewer parts/hr.

Use of stack molds is another example of technology designed to boost throughput while decreasing energy requirements. A 2-by-8 stack mold in a 300-ton hydraulic-clamp machine processes twice as many pounds per hour of material and uses substantially less electricity than an eight-cavity single-face mold in the same machine (Fig. 7).

The use of automated parts-handling devices—robots—can also help to increase throughput by reducing the cooling cycle requirements in the mold. ■

ENERGY EFFICIENCY IN INJECTION MOLDING

BY

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FOR

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Annual Technical Conference
Boston, Massachusetts
May 1981

INTRODUCTION

The central operation in reciprocating-screw injection molding of thermoplastics is the conversion of the feedstock from the solid phase, normally in pellet or granular form, to a thermally and physically homogeneous melt followed by a forming operation and a subsequent resolidification of the polymer. The phase change is brought about by energy transfer to the material from two main sources- the heated barrel and the drive mechanism. In addition, energy transfer occurs during the forming and resolidification processes.

A certain minimum energy consumption in injection molding is inevitable, being associated with the necessary phase change and forming of the polymer, and is determined by the thermodynamic characteristics of the material being processed. However any device such as a reciprocating-screw injection molding machine must always operate at less than 100% thermodynamic efficiency which results in a higher energy consumption than the theoretical minimum. In addition, these machines are required to produce useful motions which also consume energy.

As energy costs continue to rise, it becomes increasingly important to minimize energy consumption during polymer processing operations to the extent that this does not detract from product quality and productivity, and it is the goal of most processing machinery manufacturers to design equipment that operates at as high an energy efficiency as possible. At the same time, however, machine flexibility should not be compromised.

The efficiency of a process can be increased by minimizing any inherent energy losses, and a very useful tool in this respect is an "energy balance" approach to the process which can be used to derive the overall process efficiency, and highlight areas of potential energy savings.

At the 1980 NATEC, a paper was presented that detailed the "energy balance" approach to both continuous extrusion and injection molding (1). The present paper presents the results of a study of injection molding of thermoplastics in which this approach was used to characterize the efficiency of the process for two dissimilar modes of operation, each using two different polymers. Based on this, we have been able to identify areas relating to both machine operation and design in which energy losses can be minimized with a corresponding improvement in efficiency and reduction in operating costs, and these findings are being utilized in our continued program of machinery development.

EXPERIMENTAL EQUIPMENT AND PROCEDURE

The experimental study was undertaken in our Research and Development laboratory utilizing a standard HPM 220 MK IIV 14 molding machine rated at 220 ton clamp force and a nominal 14 oz. (GPPS) shot size. The particular machine used was equipped with a 26:1 Length: Diameter Ratio vented barrel, a 26:1 general purpose two stage screw, and a rotary shut-off valve assembly.

The two polymers used for the study were a General Purpose Polystyrene (Dow 678 U, 11. 0 MI) an amorphous material, and a High Density Polyethylene (Phillips TR 880, 18. 0 MI) a crystalline material. Although these materials would not normally need to be processed on a vented barrel molding machine, we chose to do so since a secondary objective of the study was to interpret the energy transfer processes in the barrel in conjunction with screw design, and the barrel heat zones on the 26:1 barrel used correspond with the four functional zones of the 26:1 two-stage screw (namely feeding, melting, decompression and recompression) as described elsewhere (2). However, it should also be noted that two-stage screws are generally designed to operate at lower solids feeding rates than are conventional single stage screws.

The machine was operated under simulated molding conditions with a 8-1/2" high steel test block installed in the mold space, and with the injection unit pivoted approximately 30° off-line. This enabled shots to be collected in a water bath or when required in an insulated collecting cup where the bulk mean melt temperature could be measured using a hand held pyrometer. One feature of this configuration that should be recognised is that the tip of the barrel and the rotary shut off valve assembly were exposed in free space, rather than covered by a 270° purge guard as in normal operation. This resulted in higher convection losses to the environment from this region of the barrel and rotary shut-off valve assembly than in normal operation. This is taken into account in the subsequent process analyses.

In order to allow a representative injection pressure to be developed, a small diameter orifice nozzle tip was used. Also, a simulated 50% maximum ejector load was applied by restricting the flow through the hydraulic return line.

High precision mercury capillary thermometers (graduated in 0.1°C. increments) were used to monitor the feed throat cooling water inlet and outlet temperatures, and the feed throat cooling water flow rate was measured with an integrating flow meter. In order to ensure a high level of precision in the flow rate measurements, a high flow rate was necessary, which led to higher process cooling energy losses than would normally be expected. This, too, is accounted for in the subsequent analyses.

The outputs of position transducers, for clamp, ejector and screw position, and pressure transducers, for clamp, ejector, injection screw motor supply and back pressure, were recorded on an eight-channel oscillograph recorder.

Power consumption was monitored by a JEM Model 312B-06-D Watthour/Varhour demand meter (Scientific Columbus) which was connected to the machine power supply lines. This provided the capability of continuous integration of the supplied electrical power (which enabled average supply power to be determined over each defined test period), and in addition , provided an analog output recorded on a high speed pen chart recorder which enabled monitoring of instantaneous power requirements. Individual heating zone energy inputs were determined by integrating the "heat on" time during each test by an instrument of our own design and construction.

Turning now to the chosen operating conditions, it was our intention to study energy efficiency during a reasonably typical molding cycle for each material, and in this instance, we operated at an approximate 25% shot size on a fairly fast cycle characterised by a high screw speed, short injection time and fairly short clamp stroke. These experiments are subsequently referred to as "Test A" and "Test C", for GPPS and HDPE respectively. It is noted that we did not attempt to particularly optimise the setup either from an energy consumption or productivity stand point. In addition to these experiments, however, we operated with a rather extreme cycle for each material at a nominal 75% shot size, characterized by a long cycle, moderate screw speed, long injection time and long clamp stroke, analogous to a situation utilizing a warm mold requiring extended packing and part cooling times, and with a deep draw. These experiments are referred to as "Test B" and "Test D" for GPPS and HDPE respectively, and again no particular attempt was made for process optimization other than the use of realistic machine settings.

The process conditions are fully detailed in Table I, and our findings are analyzed as follows.

OVERALL ENERGY BALANCE

Injection molding is a discontinuous process and different energy transport mechanisms are predominant at various points in the cycle. These are strongly influenced by the polymer being processed,by the molding conditions required, and by the cycle proportions. It is important to note that shot preparation and part forming are independant, and generally occur at different points in the cycle and at different rates.

Shot preparation is generally performed by a reciprocating screw which melts and delivers material to a region downstream of the screw tip. When a sufficient quantity of material has been accumulated in this region, screw rotation ceases. During screw rotation, the polymer is melted by conductive energy transfer from the heated barrel, and by conversion of the mechanical work of the screw drive to thermal energy in the polymer by the process of viscous dissipation.

The forming operation takes place when the screw is forced axially forward in the barrel and displaces material into the mold cavity. Energy is expended in transferring the material into the mold, but in addition, the motion of the screw relative to the barrel induces shear melting of the polymer entrained in the screw flight, while at the same time, heat transfer from the barrel provides additional energy for melting.

Finally, the screw may remain idle in the barrel while the part is cooling and/or being ejected. During this time, still further melting of the polymer entrained in the screw channel can occur due to energy conduction from the barrel.

Although the injection molding process is rather complex and is governed strongly by transient effects, it is fortunately well understood qualitatively (3, 4) and very amenable to the energy balance approach.

The theoretical energy required for melting and forming the product during a molding cycle can be expressed as follows:

$$E_T = M\int_{T_1}^{T_2} C_p . dT + \int_0^{t_i} p . \dot{Q} . dt \qquad (1)$$

Where E_T = Total net energy to polymer (per cycle)
M = Mass of shot
T_1, T_2 = Screw inlet and discharge temperatures
C_p = Specific heat capacity of polymer
p = Injection pressure
$\dot{Q}$ = Volumetric injection rate
t_i = Injection time

The first term on the right hand side of equation (1) is the energy required for shot preparation, and the second term is the energy required for forming.

In our study, the stratagem of measuring the temperature of the melt after injection through the nozzle into a collecting vessel provided a very convenient method for determining E_T. In this situation, the forming energy in equation (1) is dissipated into the melt by shear heating during injection and thus the enthalpy change from the cold feedstock to the collected shot is a direct measure of E_T; ie. equation (1) can be reformulated as:

$$E_T = M\int_{T_1}^{T_3} C_p . dT \qquad (2)$$

Where T_3 = Bulk mean temperature of the collected shot.

The overall process efficiency of the injection molding process (η_p) can be defined as:

$$\eta_p = \frac{E_T}{E} \times 100\% \qquad (3)$$

Where E = Total energy supplied (per cycle)

Consequently, from measurements of the energy supplied during each cycle and from knowledge of the thermodynamic properties of the polymer,overall process efficiencies were calculated for each experiment, as shown in Table II.

By the simple procedure of switching the heater bands off for a few cycles after running the main body of each experiment we obtained power traces from the analog output of the wattmeter, as shown in Figure 1., which were integrated numerically to reveal the power consumption of the machine systems excluding resistance heaters. The difference between this and the power consumption measured with the heat on enabled the heater energy to be calcualted. This information is also shown in Table II.

It can be seen that the extreme cycles, Tests B and D, exhibited quite low process efficiencies, 6.05% and 9.16% respectively, indicating considerable energy losses. The more typical cycles, Tests A and C were approximately twice as efficient, 15.09% and 19.29% respectively, but still indicate significant losses. Unfortunately, process efficiencies of this order of magnitude are fairly typical in the industry. Two recent publications (5,6) provide information for competitive machines in the same general clamp tonnage range (200 to 250 tons) at comparable material throughput rates as in our Tests A and C. Although sufficient data was not available in either publication for a definitive comparison, we have assumed typical ranges of specific useful work (ie specific enthalpy) to compile the Order-of-Magnitude Process Efficiency Comparison shown in Table III. We infer that the published injection molding cycles fall in the 11.6 to 21.9% process efficiency range, subject of course to the validity of our assumptions, and our test results are therefore very typical for the industry.

It should be noted, however, that the previously defined overall process efficiency (η_P) may not be a truly representitive measure of the energy efficiency of an injection molding process since in addition to the energy requirements of shot preparation and part forming, a certain energy expenditure is inevitable in the generation of desired machine motions, such as clamp opening and closing, and part ejection. This expenditure arises from friction inherent in any real life motion together with unavoidable losses in supplying the energy to produce the motions. A modified version of overall process efficiency, referred to as intrinsic process efficiency (η_I), can be determined as follows. Recognizing that the total energy supplied to the machine (E) contains the energy expended to produce required motion, a more useful denominator in equation (3) is a reduced total energy (E_R) such that equation (3) becomes:

$$\eta_I = \frac{E_T}{E_R} \times 100\% \qquad (4)$$

Where E_R = Total energy supplied (E) - energy realized in generating motions

For our experiments, we defined the energy realized in generating motions to be the work done in cycling the clamp and ejectors, which was calculated by numerical integration of clamp pressure with respect to clamp position, and ejector pressure with respect to ejector position as measured on pressure and position chart recordings, such as shown in Figure 2. This enabled intrinsic process efficiencies to be calculated as shown in Table IV. As is evident, very little energy was required to produce clamp and ejector motion, and so the values of intrinsic process efficiency are very similar to those of overall process efficiency in the present instance.

BASIC MACHINE SYSTEMS ENERGY CONSUMPTION

Numerical integration of the instantaneous power requirement curves obtained with the heaters switched off, such as shown in Figure 1., enabled the energy consumption for various functions to be evaluated, as shown in Table V.

Depending upon the molding conditions, the various functions consume different proportions of the overall energy utilized. However, much of the low energy efficiency found in the experiments is related to the overall machine loading.

The short cycle tests, A and C, exhibited an average power consumption of approximately 70% of the main motor rated power, and the long cycle tests, B and D, exhibited approximately 50% of this power . In fact, approximately 80% of the cycle for Tests A and C consumed less than 70% of the rated power, and for Tests B and D, approximately 60% of the cycle utilized less than 40% of the rated power

Operating electric motors and hydraulic pumps much below rated output generally reduces efficiency. Indeed, an electric motor operating without load can draw between 40 and 50% of its rated power (6), and an idling hydraulic pump can draw several horsepower (7). In addition, fixed losses in the system, such as the energy required to maintain pilot pressure, line losses, and oil slippage consume a relatively higher fraction of the total energy, and thereby further reduce efficiency.

A great deal of effort has been expended in recent years to alleviate the magnitude of energy losses inherent in operating at low overall machine loadings by the machinery manufacturing industry, and current designs are significantly more efficient than previously. In particular, using smaller motors capable of short periods of overloading enables higher motor efficiencies to be realized, and our design approach in this respect is similar to that described in Ref. 6. The use of divert circuits avoids losses due to pumps idling, and drop off from injection high volume pumps after a fixed time period avoids the waste of blowing a large volume of high pressure oil over a relief valve. These approaches are described elsewhere (7).

By the use of these and other design techniques, it has been possible in recent years to down size molding machine power ratings. Table VI shows an example of a range of machine sizes from 200 to 500 ton clamp force that have been reduced in power rating by 16.7 to 33.3% while maintaining comparable or improved specification, thereby enabling operation during typical cycles at higher efficiency.

However, it should be noted that process efficiencies are still generally quite low throughout the industry as a whole, and fairly radical departures in design concepts are being evolved to make further major improvements in efficiency.

PLASTICATING UNIT ENERGY BALANCE

The performance of the plasticating unit is central to injection molding , and is a major influence on both the productivity and efficiency of the process. An inadequate screw design might result in an overheated melt unless operated at slow speed, or with excessive heat losses to the barrel. Alternatively, a poor design could provide insufficient melting or mixing, and thereby limit the operation of the machine to inefficient conditions.

In fact, in most situations, shot preparation represents the largest individual energy consumption of all the functions of the molding machine. In the present studies, 50 to 60% of the basic machine systems' energy was consumed during shot preparation, in addition to the heaters' energy consumption. It was our objective, therefore, to utilize the energy balance approach to study the plasticating unit and determine its energy efficiency, and identify areas of potential improvement.

The overall plasticating efficiency (η_{pl}) can be determined as follows:

$$\eta_{pl} = \frac{E_s}{E_p} \times 100\% \qquad (5)$$

Where E_s = Energy required for melt preparation (per cycle)

E_p = Energy supplied to plasticating unit (per cycle)

In the present instance, we could determine the energy required for melt preparation (E_s) by subtracting the energy expended during injection (calculated from the integral of injection pressure with respect to screw position) from the total energy entrained in the polymer (E_T), since from equations (1) and (2) :

$$E_s = E_T - \int_0^{t_i} p \cdot \dot{Q} \cdot dt \qquad (6)$$

The energy supplied to the plasticating unit was evaluated by summing the energy supplied to the barrel and rotary shut-off valve assembly heater bands and the hydraulic energy supplied to the screw drive motor. This enabled plasticating efficiencies and energy losses to be evaluated, as shown in Table VII.

It is apparent that plasticating efficiency is higher than the previously determined overall process efficiency for each case, due in part to the fact that losses in the main electric motor and pumps are not considered in evaluating plasticating efficiency. It can be seen too that as cycle time increased and screw speed decreased, the plasticating efficiency decreased from 45% to 25% when processing GPPS, and from 50% to 30% for HDPE.

We were able to account for the plasticating unit energy losses, shown in Table VIII as follows. The feed throat cooling losses were calculated from our measurements of water temperature and flow rate, and the drive motor return line losses were evaluated from measurements of drive motor outlet pressure and oil flow rate. The inherent back pressure loss (ie the energy required to force oil from the injection cylinder) was calculated from the integral of injection cylinder pressure with respect to piston position, and the mechanical friction loss incurred in physically retracting the screw and injection piston had been determined in previous studies in which we had monitored both melt pressure downstream of the screw tip and in the injection cylinder during screw retraction.

In order to determine the thermal losses from the barrel and rotary shut off valve assembly to the environment, which we loosely refer to as "convective" losses since this is the dominant mechanism although some conduction and radiation losses are also included, we constructed the convective energy loss curves shown in Figure 3. These were obtained by monitoring the equilibrium power requirements for each zone necessary to balance the losses at a series of setpoints,ie by determining the power requirements to maintain the mass of the screw,barrel and rotary shut-off valve assembly at these setpoints. From these curves, the convective losses could be established for Tests A through D. Consequently, the motor losses could be determined by subtraction of the other losses from the known total losses.

It should again be emphasized, however, that due to our particular experimental setup, we incurred higher convective and feed throat cooling losses than would be experienced in practice. As a result, the plasticating efficiency, overall process efficiency and intrinsic process efficiency values calculated are lower than would occur in practice.

From knowledge of the energy transfer processes in the plasticating unit, it was possible to evaluate the efficiency of the screw drive motor for the different experiments as shown in Table IX. As might be expected, the fairly high drive efficiency of approximately 80% in the short cycle Tests A and C drops to approximately 55% as the screw speed, and motor loading, are reduced in Tests B and D.

Finally we used the energy balance to determine the relative contributions of barrel heating and screw drive power to melt plasticating, as shown in Table X. of particular interest is the observation that the bulk of the plasticating energy is supplied by the screw drive in each case, further emphasizing the need for particular attention to be paid to screw design in injection molding.

Of note, too, is the fact that only the order of 10 to 30% of the energy supplied to the heaters is transferred to the polymer, with the remainder being lost to the surroundings. This emphasizes that particular attention is necessary in machine design to avoid thermal energy loss, and care should be taken in selecting temperature profiles during molding.

It should be recognized that simply insulating the barrel to reduce thermal losses can lead to processing problems. For example, referring to the information for Test A in Table X, it can be seen that both the feeding and recompression zones are experiencing a net heat transfer from the polymer. If these zones were to be insulated, then the barrel temperature in each case would increase until an equilibrium was achieved where thermal conduction to neighboring barrel zones was equal to the heat transfer from the melt. This could lead to erratic feeding due to an excessively hot feed zone, and an overheated melt in the recompression zone. Consequently, caution is necessary when proposing barrel insulation as a solution to thermal energy losses, and should only be undertaken in conjunction with consideration of screw design. It is noted that in the present instance, a two stage screw would not normally need to be used for processing the materials used in the study, and a more optimum screw would be recommended that would alleviate any temperature override problems.

CONCLUSIONS

We have demonstrated how an energy balance approach to reciprocating-screw injection molding may be used to evaluate the energy efficiency of the process, to determine the magnitude of potential energy savings, and to highlight areas of machine design and operation where these savings should be sought.

In general terms, the state-of-art of injection molding can result in low efficiency with respect to energy utilization, where machine loadings are quite low in comparison with design specifications. It is apparent that under utilizing a high powered machine will incur economic penalties both in initial capital expenditure and, long-term, in the cost of lost energy. We believe that it is most important in selecting a machine for any polymer processing operation that specifications be very carefully established with the machinery manufacturer to minimize energy inefficiency.

However, it is also very important that machines retain flexibility for a range of molding conditions that may be experienced, for example in a custom molding operation. In these cases, an economic balance must be drawn between machine capabilities and energy consumption, because overemphasizing energy efficiency could lead to some reduction in productivity.

In any event, it is clear that care must be taken by the machine user to set up the machine carefully in such a way as to minimize energy losses. For example, timer settings should be established so that pumps are not under load for longer than necessary, and pressure settings should be as low as possible. If a screw is being used which is incapable of adequate melt preparation without the use of excessively high barrel temperatures, a significant saving in energy could be realized by using a high performance screw design at a lower barrel temperature, since only a small proportion of the barrel energy is actually transferred to the polymer. Also, a high performance screw can enable lower melt temperatures to be used, which can reduce both plasticating energy requirements and cycle time, and can also enable downsizing of injection units which reduces thermal losses.

Overall, we believe that the continuing escalation of energy costs will lead to significant changes in injection molding machine design concepts, which will prove to be of great benefit to both machinery users and to the plastics industry as a whole.

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POSSIBILITIES WHEREBY THE MACHINE SETTER CAN INFLUENCE THE ENERGY CONSUMPTION OF THE INJECTION MOULDING PROCESS

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How the machine setter can influence specific energy consumption in injection moulding

Injection moulding is one of the most important plastics processing techniques. Continuous further development of this technique has moreover succeeded in constantly opening up new and larger applications for the method, in spite of the difficult cost situation. In recent years, the major developments in the machine sector have been particularly achieved in respect of controls and instrumentation, electronics and hydraulics.

In view of constantly rising energy costs, the energy consumption of the injection moulding process is becoming evermore important. This paper proposes to examine to what extent energy consumption can be influenced by the moulder himself and especially by the machine setter. To do so, it is necessary to analyse the injection moulding process in respect of the energy consumption points.

1. Energy consumption and energy losses in an injection moulding machine

On measuring the energy consumption for plasticising a given amount of plastic per unit time in an injection moulding machine and comparing the found value with the calculated value of the energy required to melt the same amount of plastic and bring it to the same processing temperature, it becomes clear that the actually required energy is substantially greater than the theoretically required value. The cause lies in losses during plasticisation, resulting from mechanical, electrical and hydraulic efficiencies, radiation losses and, for example, cooling of the feed bush. Figure 1 shows this comparison for a polycarbonate moulding. If we take the actually measured plasticisation energy as 100%, the diagram shows that the theoretically required value is only 32.6% of the measured energy consumption.

Accordingly, to lower the energy consumption, it is necessary to minimise the energy losses. Whilst a proportion of these losses can be influenced by the machinery manufacturer providing a suitable machine design, the moulder and in particular the machine setter can also substantially influence the energy consumption of the machine.

Figure 2 shows, for a diagrammatically represented injection moulding machine, at what points of the machine energy is supplied and at what points energy is consumed. The figure also clearly shows where and how the moulder, in particular, can influence the energy consumption.

The energy balance is often represented by means of a Sankey diagram which illustrates how the total power taken up during a process again leaves the process (Figure 3). Taking the example of an injection moulding machine, the energy taken up leaves the system via mould cooling, oil cooling, cooling of the intake zone, convection and radiation.

Figure 4 depicts the quantitative make-up of the energy supplied and energy discharged. The large scatter of the figures quoted shows that there must be a range of factors which influence energy consumption. We can see that the energy supplied is essentially taken up by the screw drive, the drive of the hydraulics, and the cylinder heating. The energy is discharged particularly via mould cooling, oil cooling, convection and radiation, and cooling of the intake zone.

2. Some important parameters in energy consumption

Certain parameters, which can now be dealt with, are important factors in the energy consumption of an injection moulding machine.

The energy costs for which the moulder has to pay the electricity board are made up of the basic tariff and the actual energy consumption. The basic tariff imposed by the electricity board on the moulder is the peak load in moulding operation, summed over 15 minutes. The value found serves as the basis for the power supply made available. Accordingly, load peaks in moulding operation should be minimised.

For the electricity board, the basis of calculation is the actual energy consumption in the form of work performed [dimension kWh]. A parameter which indicates the costs arising is accordingly the energy consumption in kWh per hour, which has the dimension $\frac{kWh}{h}$.

To calculate the energy costs arising per moulding, it is helpful to convert the energy consumption to an amount per shot. This can have either the dimension

$$\frac{kWh}{cycle}$$

or

$$\frac{Wh}{cycle}$$

Since here the energy consumption is related to one injection cycle, it is also referred to as the "specific" energy consumption.

If the energy consumption is related to unit weight, we obtain a specific energy consumption having the dimension

$$\frac{kWh}{kg}$$

or

$$\frac{Wh}{g} \quad \text{fig. 5}$$

This specific energy consumption thus gives particularly clear information on how economically the plastic is being processed on an injection moulding machine.

3. Effect of machine design on energy consumption

In the past, numerous investigations and publications have shown how machine design influences energy consumption, in particular specific energy consumption. Battenfeld has developed machine designs, both for the HK series and the S series, which allow particularly low values of the specific energy consumption to be achieved. On machines of the S series, in particular, numerous measurements were carried out on customer premises under production conditions, and these measurements confirmed the special advantages of the machine design. By virtue of the hydraulic accumulator system used for all movements, the two-stage hydraulic clamping system, which has only a low oil requirement, and the electric motor screw drive, the measured energy consumption of machines of the S series (Figures 6 and 7) was, for equal performance, up to 50% lower than with competitors' machines. Figure 8 shows the consumptions measured in production of a bathroom cabinet body. For a given cycle time, the energy consumption for the drive and the heating, and accordingly the total energy consumption, was first measured on a fully hydraulic injection moulding machine with 8,000 kN clamping force. Production was then run under identical conditions on a Battenfeld BSKM 8000/1050 S machine. Though the Battenfeld machine used was one stage larger both in respect of the clamping unit (10,500 kN compared to 8,000 kN) and the injection unit (8,000 as against 4,600 according to Euromap), as is also shown by the technical data in Figure 8, the energy consumption measured when using the Battenfeld machine was 16.7% lower. This saving becomes particularly clear when converted to the costs saved per annum. Assuming an energy price of 15 pfennig per kWh and 5,000 hours, the use of an energy-saving machine means, in the case investigated, a cost saving of 7717.98 DM per annum. The comparison proves even more in favour of the Battenfeld machine if both screw cylinders are provided with cylinder insulation. In the example investigated, only the competitor's machine had cylinder insulation. These measurements show that when using injection moulding machines of the same size and comparable fitments the energy costs can be lowered by about 25% by using the Battenfeld machine, amounting to a cost saving of about DM 12,000 per annum under the conditions described above.

In investigating the energy consumption as a function of time for the comparison in Figure 8, it is found that the lower energy consumption for the Battenfeld machine is above all due to the lower energy consumption when idling (Figure 9). The graphs of the high-speed pen recorder used show the energy consumption with the exception of the heating. The low energy consumption when idling is achieved in the Battenfeld machine by the particular design of the drive.

Figure 10 shows the measured specific energy consumption for some mouldings. The mouldings investigated, made from the raw materials polyethylene, polypropylene, polystyrene and polycarbonate, require a specific energy consumption of 0.33 to 1.0588 kWh per kg. We shall deal later with the causes of these large differences.

4. Influencing the energy consumption through the processing parameters

It may be expected that the processing parameters, for example the material temperature, injection pressure, back-pressure, cycle time, etc. influence the energy consumption. How great this influence is in absolute figures or percentages depends very much on the machine system. Accordingly, no universally valid guideline data can be given. Guideline data can only be determined for a particular machine system.

Measurements were carried out on machines of the S series with the aim of revealing the essential factors which influence energy consumption. Figure 11 shows, on the graph of a high-speed pen recorder, how the energy consumption points of the drive system interact. First, it can be seen clearly that the need for low energy consumption during idling is met; energy consumption during idling is only 10% of the energy consumption under maximum load. As soon as the hydraulic accumulator is being charged by the constant-delivery pump, the energy consumption increases. The shape of the curve is the same for switching-on and switching-off of the pump, as is the peak value of the energy consumption. Depending on how long the accumulator-charging pump is switched on, the area on the diagram is smaller or larger. During plasticisation, ie. during rotation of the screw (effected, in the case of the machines of the S series, by means of a pole-change electric motor), increased energy consumption is again noted.

Figure 12 shows an investigation, for a machine of size BSKM 800/220 S, of how a change in processing conditions influences the energy consumption. First, an "optimum" moulding was produced from polystyrene, and thereafter important setting parameters, eg. the pressure-hold time, cycle time, magnitude of the holding pressure, clamping pressure, mould-filling time and weight were varied. For comparison, the same moulding was also produced from polypropylene. The diagram (Figure 12) shows the measured energy consumption of the drive, plotted as specific energy consumption in

$$\frac{\text{kWh}}{\text{cycle}} \text{ and in } \frac{\text{kWh}}{\text{kg}}$$

It can be seen clearly that the cycle time, the weight and the raw material substantially influence the energy consumption. Changes in the pressure-hold time, the magnitude of the holding pressure, the clamping pressure and the filling time produce only little change in energy consumption. The differences result from the oil leakage losses under different operating conditions. The reason why these setting parameters have only little influence on energy consumption is to be found in the machine design of the S series with hydraulic accumulator system. A particular feature of the hydraulic accumulator system is that the initial state is the same for each cycle both in respect of the amount of oil and of the oil pressure of the hydraulic accumulator. Accordingly, changing these values only influences the specific energy consumption through the different leakage oil losses. Hence, setting errors in the parameters described above have, given the machine design of the S series, no significant adverse effect on energy consumption.

The diagram in Figure 12 however shows clearly that the cycle time, the weight of moulding and the raw material used influence the specific energy consumption.

a) Cycle time

The cycle time should be as short as possible, not only in the interest of maximum output from the machine but also, as has been seen, in the interest of low specific energy consumption. As Figure 13 shows, the difference in energy consumption in particular results from the energy consumption occurring during idling. Hence, the cycle time should be kept as short as possible.

b) Weight

We have already shown, in Table 10, that the specific energy consumption for different plastics can vary substantially with size of machine. These large differences can be better understood if the mouldings produced are shown in relation to the machine size. This can be done most simply by relating the weight of moulding to the maximum shot weight of the machine. The values found, shown in the table in Figure 10, are shown again in Figure 14, this time after determining the ratio of weight of moulding to maximum shot weight of the machine, both for polyethylene and for polypropylene mouldings. Though different machine designs were used - namely, machines of both the HK series and the S series - it can be seen clearly that in those cases where a high specific energy consumption was measured the utilisation of available shot weight was also very low. As soon as machine utilisation is more favourable, the specific energy consumption values are also substantially more favourable. However, the examples shown in Figure 14 make it clear that not only the utilisation of available shot weight, but also the cycle time as already examined earlier, have a substantial influence on specific energy consumption. This explains that even at roughly comparable machine utilisation (58 as against 59%), greatly differing specific energy consumptions can be measured.

c) Raw material

It is well known that the melting of different plastics entails different energy consumptions. In most cases, however, the moulder cannot influence the raw material used. Figure 15 shows the drive energy for processing of polystyrene and of polypropylene. The shaded areas show the energy consumption for the extruder drive. Whilst planimetric measurement of the areas shows that the energy consumption of the extruder drive is greater for polypropylene, the difference between polystyrene and polypropylene becomes all the more clear when the found value is converted to specific energy (kWh/kg). The heating energy is also greater for polypropylene than for polystyrene.

If, however, we take into account that because of the low specific gravity of polypropylene, the same moulding weighs less when made from this raw material, the differences again become markedly smaller. This example is intended to show that it pays particularly for the moulder to concern himself with the raw material question. In some cases, substantial reduction in energy consumption can be achieved by appropriate fillers and reinforcing agents.

The energy consumption can also be influenced through the material temperature and the screw speed. As a matter of principle, the material temperature should be low. A low material temperature not only means low energy needed to melt the plastic, but also low energy to be removed again from the plastic via the mould. The screw speed must also be considered in conjunction with the material temperature. In principle, the screw speed should be as low as possible, so that, in conjunction with the chosen low material temperature, a low energy consumption is achieved. Of course, the plasticising time of the machine must not be allowed to become the cycle-determining factor. The optimum value of these parameters can accordingly only be established for each specific case.

The investigations of the factors influencing energy consumption were carried out on machines of the S series (from 700 kN upwards). For machines of other series, for example the HK series, the scope for influencing energy consumption through processing parameters is of different magnitude, because of the different drive design employed.

5) Further possible methods of energy saving in an injection moulding system

The moulder and in particular the machine setter have, in addition to the possibilities just examined, yet other means of energy saving, with which we shall deal next.

a) Geometrical setting of the machine

All strokes of the machine should only be as large as is genuinely necessary for production. By this we particularly mean the strokes of the clamping unit and of the nozzle. Moreover, in machines of the S series, the prescribed play between the swing disc and pressure ram, to allow the swing disc to be introduced, should not be unnecessarily enlarged. Greater play, and larger strokes in respect of the setting values described earlier, result in increased oil consumption per cycle which in turn means, in the design of the S series, that the accumulator-charging pump has to be switched on for longer periods and accordingly the energy consumption is greater. Optimising these strokes by reducing them to the lowest permissible value thus means a saving in energy.

b) Cylinder insulation

In the past, much discussion centred on cylinder insulation. By this we mean insulation of the screw cylinder, intended to reduce radiation losses. In order to be able to estimate the possible savings achievable with cylinder insulation, it is important once again to have a clear picture of the influence of cylinder heating on total energy consumption. Figure 4 has shown that cylinder heating can account for between 10 and 40% of total energy consumption. Accordingly the savings held out by manufacturers of such cylinder insulation, namely about 25% of the heating power, are still as much as from 2.5 to 10% of total energy consumption. Proof of the reduction in energy consumption in connection with heating revealed itself on comparative measurement of the energy consumption of a fully hydraulic injection moulding machine and the Battenfeld machine of the S series (Figure 8). Whilst the competitor's machine was equipped with cylinder insulation, the Battenfeld machine had the normal equipment. The measured additional heat energy consumption, 8.4%, is marked but it must be borne in mind that under the particular circumstances the Battenfeld machine being compared with the competitor's machine was larger than necessary, as is also clear from the installed heating power (80 kW against 60 kW). Under comparable conditions, a saving of about 5% would have been expected, corresponding to a saving in total energy of about 2%.

The savings of up to 25% which are held out by the manufacturers are difficult to achieve if the machinery manufacturer has already provided the screw cylinder with heater bands having a heat-insulating jacket, as is customary in Battenfeld machines. If the comparison is made with conventional heater bands without a heat-insulating jacket, undoubtedly greater savings can be achieved by providing cylinder insulation.

Figure 16 shows that even when using heater bands with a heat-insulating jacket, the energy consumption can be further reduced by insulating the screw cylinder. The table lists the measured values of the energy required to heat up the screw cylinder, on a BSKM 800/220 S machine with a 60 mm screw diameter. The temperatures of the thermocouples for the individual heating zones, also recorded in the experiment, showed virtually the identical pattern with and without insulation. Moreover, the heat required for heating up was about the same. However, with insulation the energy consumption required for heating up was markedly lower, namely 12.5% lower after 30 minutes and 10% lower after 60 minutes. These savings are the result of the low radiation losses from cylinder insulation.

Accordingly, energy savings of varying magnitude - depending on the initial state of the injection moulding machine and on the processing conditions - can be achieved by means of cylinder insulation.

c) Mould insulation

Injection moulds also suffer energy losses through convection and radiation. If it is desired to have mould temperatures lower than ambient temperature, the mould receives heat from the environment and this means that the amount of heat to be removed from the mould is increased. The extent to which energy saving can be achieved by external insulation of the mould to reduce radiation losses or to reduce heating-up by the environment becomes particularly clear in cases where the mould has to be brought to temperatures substantially above ambient temperature. This is especially the case when processing elastomers or thermosets. However, even in thermoplastic processing insulation of the mould can offer clear advantages if, for particular processing reasons, mould temperatures of between 40 and 120°C have to be used, as is customary, for example, when moulding plastics for industrial uses.

We have investigated, on examples of elastomer processing, to what extent a reduction in energy consumption can be achieved by means of external insulation of the mould or by insulation generally. The heat flux at the surface of the mould was measured as an indication of the energy saved. The results are shown in Table 17.

In the case of a heating plate, such as is employed for heating moulds for elastomer processing, external insulation produced a substantial reduction in heat flux. With the heating plate set to a temperature of 150°C, the heat flux was reduced by 64.7% of the value measured without insulation.

In the case of an elastomer mould heated to a temperature of 184°C, similar good results were achieved by using external insulation. Whilst heat flux was lowered by 32.1% when using a mineral wool insulation, the reduction achieved by insulation with asbestos cement (4 mm) was 36.7%. Particularly marked reductions in heat flux were achievable if the asbestos cement used was additionally provided with aluminium foil; this reduced the heat flux by 66.1%. These values show that substantial reductions in energy consumption, through reduction in energy losses, can often be achieved even by very simple and inexpensive means.

d) Correct setting and maintenance of the machine

In investigating how the energy consumption can be influenced by the moulder or the machine setter, we must not forget to draw attention to correct setting and maintenance of the machine. By correct setting we mean, here, not the processing parameters but the basic setting parameters of the machine. For example, an incorrectly set pump pressure or incorrectly set pump flow rate can not only influence the processing conditions adversely but also result in increased energy consumption.

Soiled filters cause increased pressure build-up in the hydraulic system and reduced flow rates from the hydraulic pumps, in turn causing increased energy consumption. In the interest of low energy consumption it is therefore absolutely essential to ensure timely machine maintenance.

6. Summary

We have shown, with examples, what measures lead to the reduction of the specific energy consumption in injection moulding. From the start, the machinery manufacturer can exert a major influence on specific energy consumption through appropriate machine design. However, by choosing an appropriate and particularly energy-saving machine, the moulder can also create favourable basic conditions for running his production with low energy consumption.

We have further shown, with examples taken from the design of the S series, that the energy consumption can be substantially reduced by minimising the cycle time. The moulder should also ensure that the injection mould is built for what is actually the most favourable machine for the particular job. We have shown, with examples, that if a low proportion of the maximum shot weight of the machine is utilised, the specific energy consumption is substantially higher. Though, because of available machine capacity and because of the jobs arising, it is often difficult to find the ideal solution in an injection moulding shop, the effect of utilisation of maximum shot weight on energy consumption clearly shows that it pays to try and seek the best possible solution in this respect.

The raw material also affects energy consumption. Often, the moulder can himself influence the raw material used.

Keeping the opening strokes and all the distances travelled by the machine to a minimum is not only a sensible measure in the interest of minimum cycle time, but also in the interest of lowest possible specific energy consumption.

Losses due to radiation can, in some cases, be substantially reduced by insulating both the screw cylinder and the mould.

The correct setting of the machine, and regular servicing, also influence specific energy consumption.

The moulder and in particular the machine setter can thus make a considerable contribution to reducing the energy consumption in injection moulding.

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Lecture No. 4

1. Comparison of measured energy and theoretically required energy for melting of polycarbonate
2. Diagram showing supplied and lost energy of injection moulding machines
3. Sankey-Diagram:
   Diagram showing used and lost energy during the injection moulding process
4. Qualitative and quantitative breakdown of the supplied and removed energy on an injection moulding machine
5. Essential parameters for energy consumption
6. Injection moulding machine, series "S"
7. Hydraulic accumulator system
8. Comparison of the energy consumption for different machine systems
9. Comparison of energy consumption as a function of time (without heating) of a fully hydraulic injection moulding machine and a Battenfeld injection moulding machine
10. Specific energy consumption for the production of injection mouldings
11. Energy consumption for the drive as a function of time on a Battenfeld BSKM 3200/500 S DS injection moulding machine
12. Effect of processing parameters on the energy consumption of the machine drive
13. Comparison of energy consumption for the extruder and hydraulic drive for 2 different cycle times
14. Specific energy consumption as a function of raw material and of utilisation of the maximum shot weight
15. Comparison of energy consumption for the extruder drive for polystyrene and polypropylene
16. Energy consumption for heating the screw cylinder (BSKM 800/220 S 60 Ø)
17. Energy saving through mould insulation
    Example: Heat flux measurements in elastomer processing

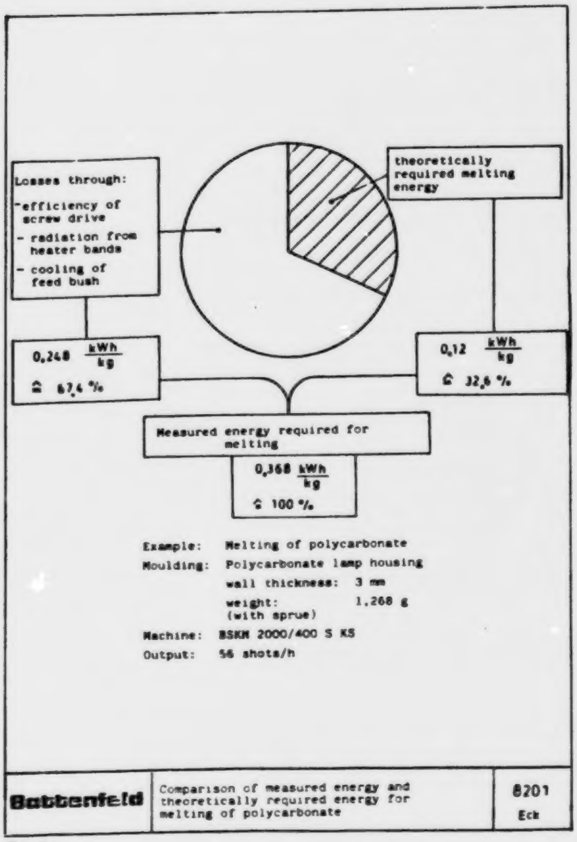

fig. 1

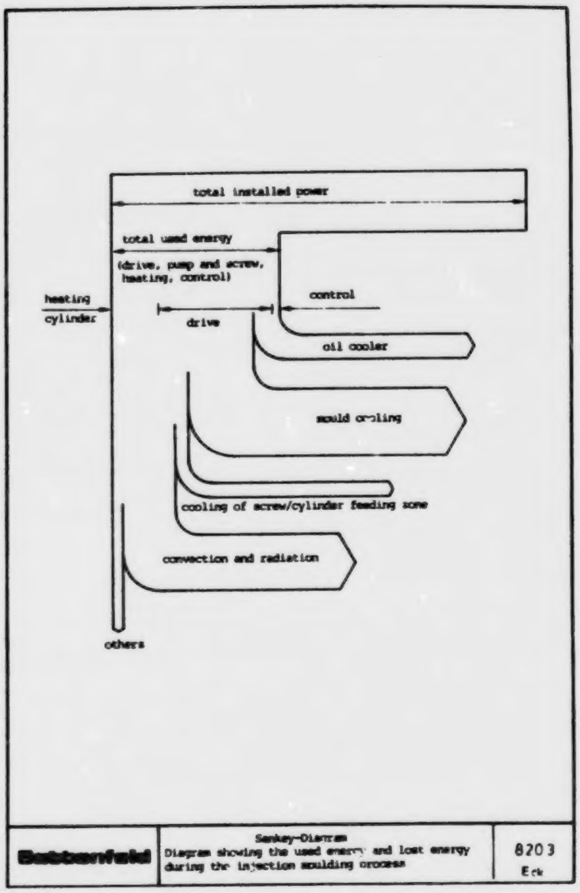
total installed power
total used energy
(drive, pump and screw, heating, control)
heating cylinder
drive
control
oil cooler
mould cooling
cooling of screw/cylinder feeding zone
convection and radiation
others
Battenfeld
Sankey-Diagram
Diagram showing the used energy and lost energy during the injection moulding process
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fig. 3

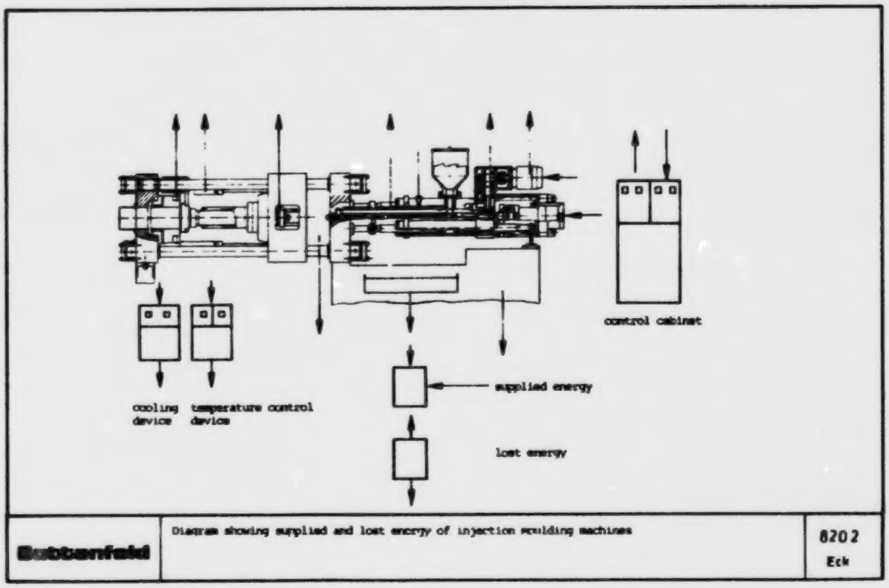
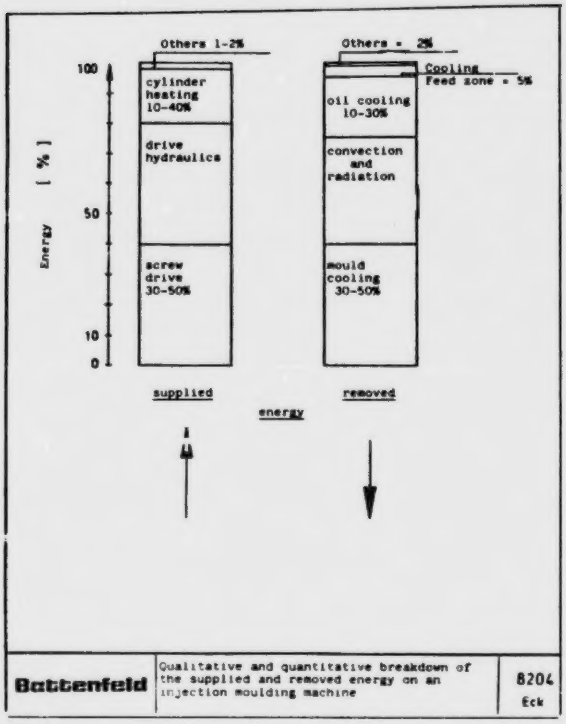
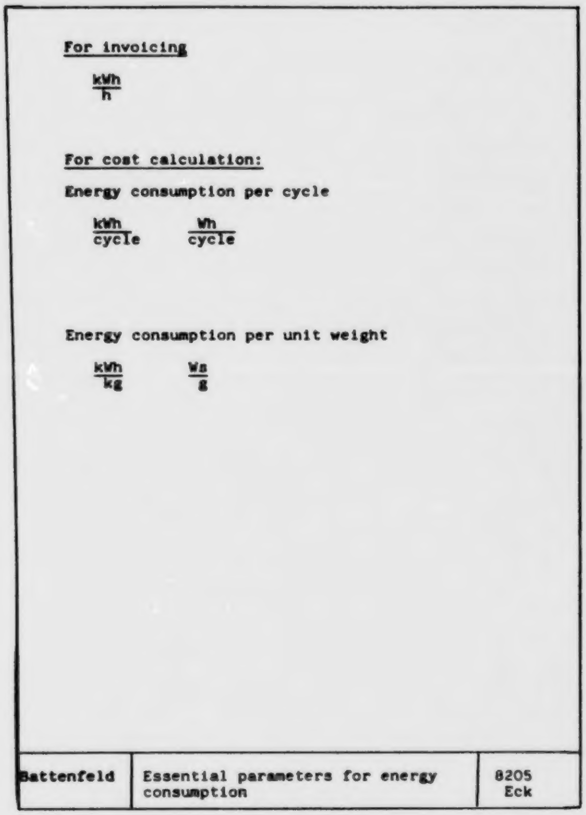

control cabinet
cooling device
temperature control device
supplied energy
lost energy
Battenfeld
Diagram showing supplied and lost energy of injection moulding machines
8202
Eck

fig. 2


Others 1-2%
Others = 2%
Cooling
Feed zone = 5%
100
cylinder heating 10-40%
drive hydraulics
screw drive 30-50%
oil cooling 10-30%
convection and radiation
mould cooling 30-50%
Energy [%]
50
10
0
supplied
energy
removed

Battenfeld | Qualitative and quantitative breakdown of the supplied and removed energy on an injection moulding machine | 8204 Eck

fig. 4



For invoicing

$\frac{kWh}{h}$

For cost calculation:

Energy consumption per cycle

$\frac{kWh}{cycle}$ $\frac{Wh}{cycle}$

Energy consumption per unit weight

$\frac{kWh}{kg}$ $\frac{Ws}{g}$

Battenfeld | Essential parameters for energy consumption | 8205 Eck

fig. 5

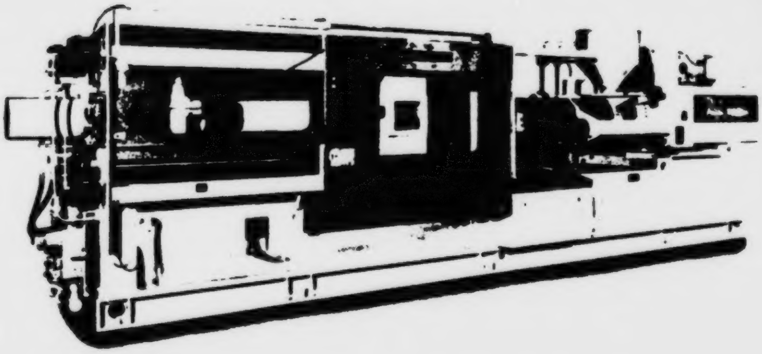


fig. 6

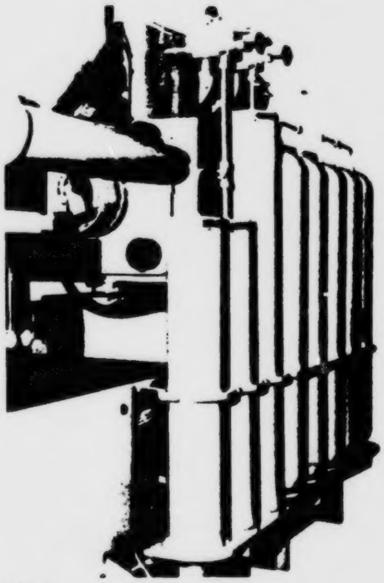
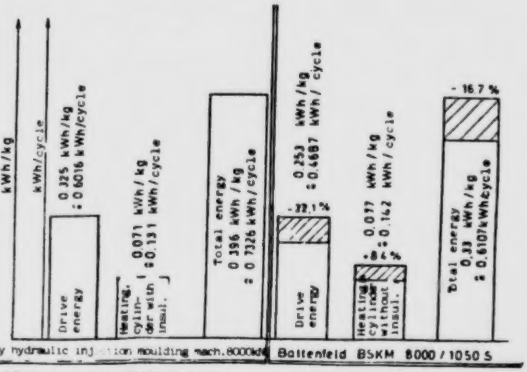


fig. 7

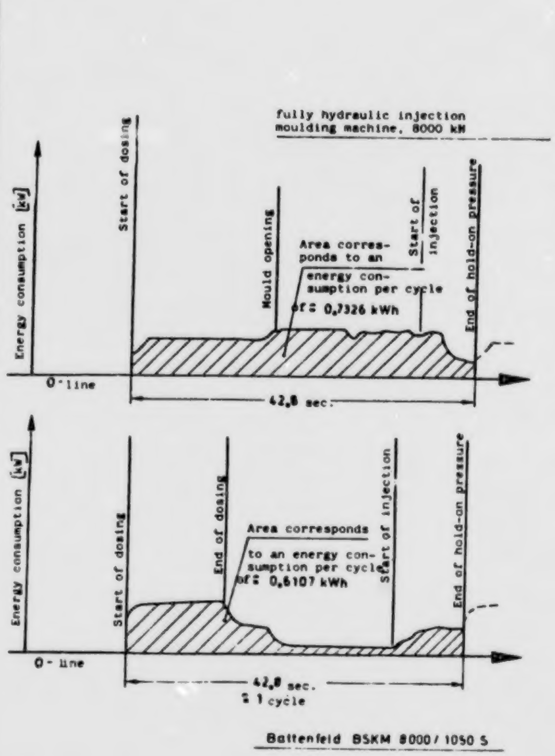
Injection moulding machine	fully hydraulic injection moulding machine, 8000 kN	Battenfeld BSKM 8000/1050 S
Injection unit according to Euromap standard	4600	8000
Clamping unit	8000 kN	10500 kN
Screw diameter	100 mm	140 mm
maximum swept volume	2560 cm³	6358 cm³
Injection cylinder heat-insulated	yes	no
Nozzle	hydraulic seal nozzle	open nozzle
Extruder drive	hydraulic motor	electric motor, pole-changeable stage II, electromagnetic clutch, motor does not switch off
Pump drive power	110 kW	40.5 kW
Extruder drive power	-	46 kW
Heating power	60 kW	80 kW
Total installed power	171 kW	166.5 kW



Moulding	Bathroom cabinet	
Weight	1850 g s = 2.5 - 3 mm	
Raw material	Polystyrene	Cycle time 42.8 s

Battenfeld | Comparison of the energy consumption for different machine systems. | 8206 Eck

fig. 8



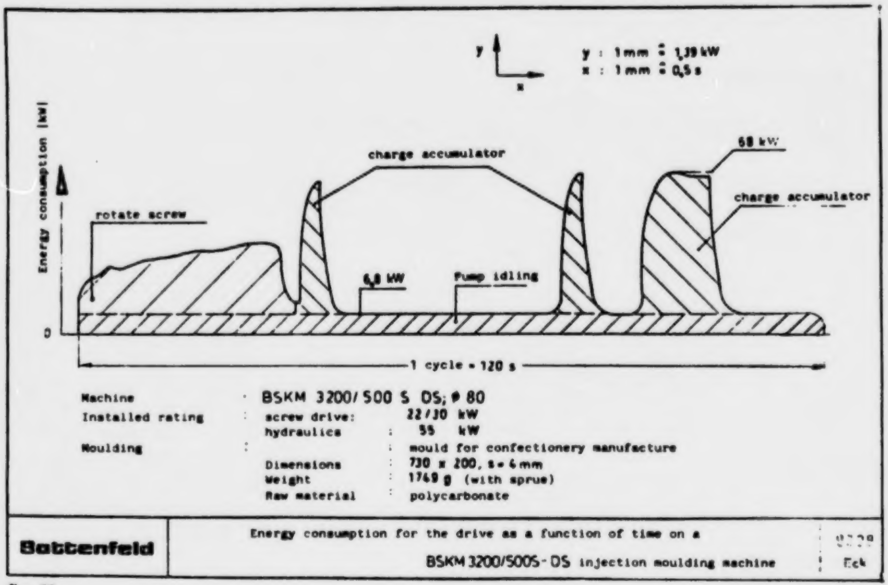
Battenfeld | Comparison of energy consumption as a function of time (without heating) of a fully hydraulic injection moulding machine and a Battenfeld moulding machine | 8207 Eck

fig. 9

SPECIFIC ENERGY CONSUMPTION FOR THE PRODUCTION OF INJECTION MOULDINGS

DATA OF ARTICLE				DATA OF MACHINE				ENERGY CONSUMPTION PER CYCLE			ENERGY CONSUMPTION PER UNIT WEIGHT		
Moulding	Weight	Raw material	Cycle time	Machine type	Clamping force	Maximum shot volume	Utilisation of max. shot weight	Drive + plasticisation	Heating	Total	Drive + plasticisation	Heating	Total
/	g	/	s	/	kN	cm³	%	kWh/cycle	kWh/cycle	kWh/cycle	kWh/kg	kWh/kg	kWh/kg
Battery housing	6.9	Polystyrene	2.7	50/30 HK ES	300	34.4	22	0.00477	0.00056	0.00533	0.691	0.081	0.772
Flower pot, 110Ø	14.5	Polyethylene	3.05	170/85 HK ES	650	113	18	0.01332	0.00203	0.01535	0.9186	0.1402	1.0588
Herring pot	21.6	Polypropylene	5.8	300/70 HK ES	700	199	15	0.01392	0.00655	0.02047	0.6444	0.3032	0.9476
1 l box	43	Polypropylene	8.4	300/100 HK ES	1000	199	30	0.02624	0.00960	0.03584	0.6102	0.2233	0.8335
Lid for bucket	59.8	Polyethylene	6.8	300/100 HK ES	1000	199	42	0.02420	0.00447	0.02867	0.4047	0.07475	0.47945
10 l bucket	610	Polyethylene	25	3200/500 S	5000	1491	58	0.2458	0.0875	0.333	0.4030	0.1434	0.5464
Confectionery mould	1749 with sprue	Polycarbonate	122.2	3200/500 S DS	5000	1491	84	0.760	0.161	0.921	0.4345	0.0921	0.5266
Stool	1785	Polypropylene	83.9	8000/850 S KS	8500	5480	45	0.5840	0.3345	0.9185	0.3272	0.1874	0.5146
Bathroom cabinet	1850	Polystyrene	42.8	9000/1050 S KS	10500	6358	32	0.4687	0.142	0.6107	0.253	0.077	0.33
12 x 1 bottle crate	1900	High density polyethylene	50	5000/850 S KS	8500	3981	67	0.5408	0.1600	0.7008	0.2846	0.0842	[illegible]
Large trough	3500	High density polyethylene	210	12500/1500 S DS	15000	8340	59	1.440	1.120	2.560	0.41	0.32	0.73

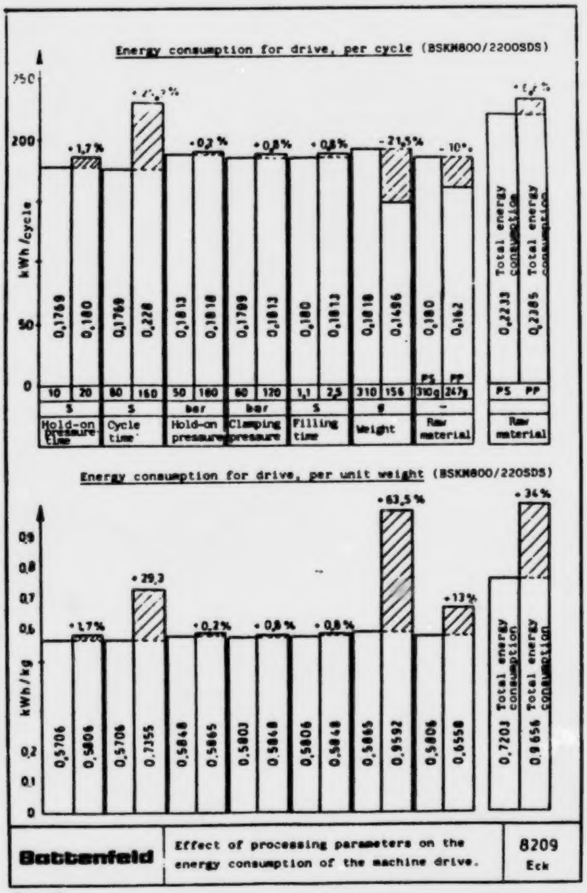
fig. 10



Machine : BSKM 3200/500 S DS; ⌀ 80
Installed rating : screw drive: 22/30 kW
hydraulics : 55 kW
Moulding : : mould for confectionery manufacture
Dimensions : 730 x 200, s = 6 mm
Weight : 1749 g (with sprue)
Raw material : polycarbonate

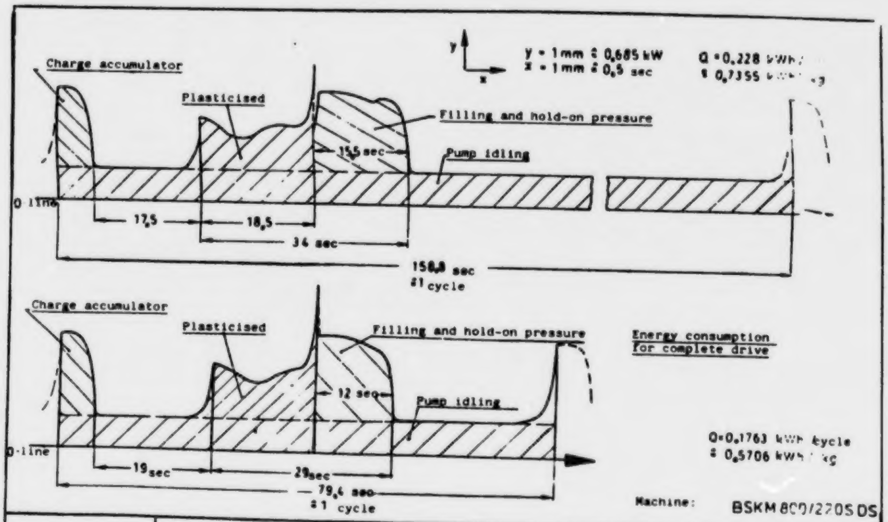
Battenfeld Energy consumption for the drive as a function of time on a BSKM 3200/500S-DS injection moulding machine Eck

fig. 11



Battenfeld Effect of processing parameters on the energy consumption of the machine drive. 8209 Eck

fig. 12



Battenfeld

Comparison of energy consumption for the extruder and hydraulic drive for 2 different cycle times.

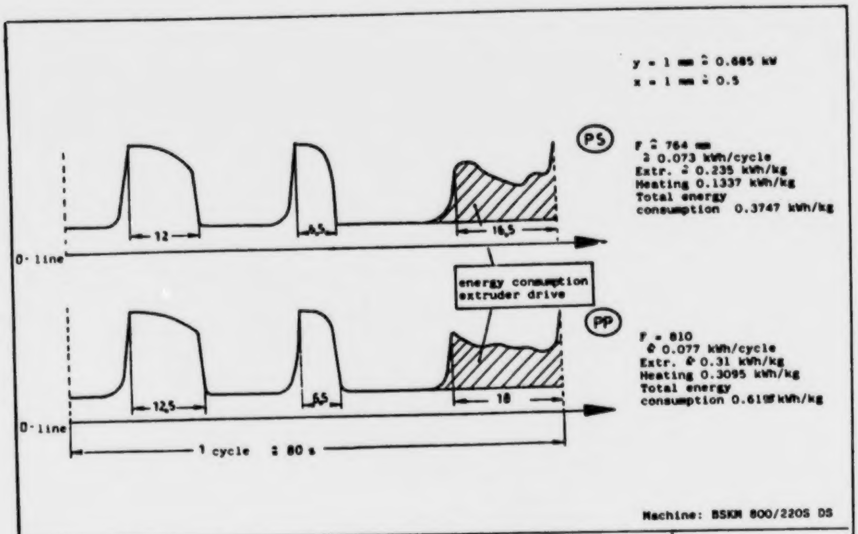
8210
Eck

fig. 13

SPECIFIC ENERGY CONSUMPTION AS A FUNCTION OF RAW MATERIAL AND OF UTILISATION OF THE MAXIMUM SHOT WEIGHT

Moulding	Weight	Raw material	Cycle time	Type of machine	Utilisation of maximum shot weight	Drive + plasticisation	Heating	Total
/	g	/	s	/	%	kWh/kg	kWh/kg	kWh/kg
Flowerpot, 1100	14.5	Polyethylene	3.05	170/65 HK ES	18	0.9186	0.1402	1.0588
Lid for bucket	59.8	Polyethylene	6.6	300/100 HK ES	42	0.4047	0.07475	0.47945
18 l bucket	610	Polyethylene	25	3200/500 S	58	0.4030	0.1434	0.5464
12 x 1 l bottle crate	1900	High density polyethylene	50	5000/650 S KS	67	0.2846	0.0842	0.3688
Large trough	3500	High density polyethylene	210	12500/1500 S DS	59	0.41	0.32	0.73
Herring pot	21.6	Polypropylene	5.8	300/70 HK KS	15	0.6444	0.3032	0.9476
Box 1 l	43	Polypropylene	6.4	300/100 HK ES	30	0.6102	0.2233	0.8335
Chair	1785	Polypropylene	83.9	8000/850 S KS	45	0.3272	0.1874	0.5146

fig. 14



Battenfeld	Comparison of energy consumption for the extruder drive for polystyrene and polypropylene	8211 Eck

fig. 15

ENERGY CONSUMPTION FOR HEATING THE SCREW CYLINDER (BSKM 800/220 S 60 Ø)

Time from start of heating-up	without insulation of the screw cylinder	with	Saving through cylinder insulation
min	kWh	kWh	%
30 min	4.8	4.2	12.5
60 min	6.0	5.4	10.0

fig. 16

ENERGY SAVING THROUGH MOULD INSULATION

Example: Heat flux measurements in elastomer processing

	Heat flux			
	without insulation	with insulation		
Type of insulation		Mineral wool	Asbestos cement (4 mm)	Asbestos cement (4 mm) + aluminium foil
Description	W/m² %	W/m² %	W/m² %	W/m² %
Heating plate, 150°C setting	1700 (100)		600 (35.3)	
Elastomer mould, 184°C setting	2210 (100)	1500 (67.9)	1400 (63.3)	750 (33.9)

fig. 17

APPENDIX G.2.

Articles on Injection Molding Machine Design and Efficiency.

1. Energy Considerations for Injection Molding Machinery
   Cincinnati Milacron Co.,
   Batavia, Ohio

2. Energy Saving Injection Molding Machine SSE System
   Nissei Plastic Industrial Co., Ltd.,
   Sakaki, Nagano-ken, Japan

3. Reducing Energy Consumption in Injection Molding Machines
   A.V. Chivers, B.A., TEng(CEI), MIE., Chief Engineer
   Bone Cravens Ltd., England
   Reproduced from European Plastic News
   October 1981

4. Taking the Heat Off Injection Molding
   B.A. Olmsted, Manager Plastics Machinery Engineering
   Reed-Prentice Div., Package Machinery Co.,
   East Longmeadow, Mass.
   Reproduced from Plastics Engineering
   November 1980

5. Variable Pumps Mean Anything to You?
   It Should. Here's Why
   Reproduced from Modern Plastics
   August 1982

6. High Energy Yield With Netstal Injection Molders
   Dr. T. Coppetti, Technical Director
   Netstal-Maschinen AG
   Nafels, Switzerland

**CINCINNATI
MILACRON**

The advent of expensive electrical power has caused increasing concern among users of injection molding equipment, about the efficiency of their machinery.

Hydraulically powered machinery is operated by means of hydraulic oil flow (rate)and pressure (force). The heart of such machinery is its electric motor and hydraulic pump system. To accomplish a specific task the requirement of hydraulic flow and pressure to operate the machine functions can be readily determined.

The basic task of reciprocating-screw injection molding machine is not fundamentally complex. A quantity of viscous polymer is prepared via screw rotation, which produces mechanical shear heat, and conductive heat from the injection cylinder heater bands. Other functions include closing the mold halves, building tonnage, opening the mold and ejecting finished plastic parts.

All functions, except conductive heat, most commonly are controlled by hydraulic oil flow and the capacity, and thus the specifications of these functions, relate directly to the rate of oil flow (gallons per minute) and the force of the oil (pressure PSI). Thus, the capacity and rate by which the task of a given machine is performed, is proportional to the electric motor-hydraulic pump size of that machine.

Questions, arise regarding machine and hydraulic configuration or energy efficiency of design. Is one type of clamp more efficient than another? What effect does hydraulic circuit design have on power consumption?

To answer the question concerning machine configuration -- it is most important to "see" where and how power is used by the machine on a typical injection molding cycle. This can be accomplished by current meters but is most descriptive and informative when an accurate power transducer and strip chart is attached to the main electrical inputs of the machine. (See Fig. 1) The strip chart is calibrated and will produce a record of actual power as the machine cycles. (Fig. 2) Any point on the curve indicates the power level at the corresponding instant during the molding cycle and is expressed in kilowatts. Since the strip chart operates at a known rate, the area under the curve is the total of the power consumed. Power for one cycle is thus obtained, and, if multiplied by the number of cycles per hour, will yield the KW per hour rate of power consumption.

The most helpful data that can be derived from these measurements is the relative amount of power used for each function of the machine, such as clamp close, clamp open, extruder run, injection high rate, and injection packing or hold.

Clamp System:

Shown in Fig. 3 and Fig. 4 , are the power consumption curve for a 250 ton hydraulic clamp machine and a 300 ton toggle type machine. The curve represents an actual production cycle for an ABS tray. The processing data is listed and is identical for both machines. The motor horsepower rating of the 250 ton clamp machine is 60 HP and is 50 HP for the 300 ton toggle machine.

Considering the power consumption of the clamp close and clamp open function, it is apparent that the power consumed for this part of a cycle is small relative to the total for the cycle. Clamp power takes the form of a sharp peak as the motor is loaded by the pump pressure required to start the clamp in motion (inertia). Once moving, pressure drops and thus power level drops. Since clamp action is a small portion of the molding cycle, so is the power consumed. In both hydraulic and toggle clamps a small volume cylinder or booster tube is used for clamp motion. Pump rate is large but speed is fast and duration is short.

A very short duration peak is experienced during clamp tonnage build-up with both toggle and hydraulic clamps. Regarding the toggle machine, this power peak is a result of pressure loading for straightening the toggle linkage and stretching the tie rods, thus building tonnage. The hydraulic clamp experiences a peak which occurs as the hydraulic clamp's column of oil is pressurized.

Comparison of the two charts verifies this similarity. The very low volume pump that is used to hold tonnage is a small load to the electric motor and produces a power level just slightly greater than the idle load of the motor. This level can be observed during the cooling portion of the cycle. If a variable displacement pump is used for clamp tonnage, holding power can be reduced further because only pressure is held with virtually no volume flow.

Upon opening, another peak occurs. This pressure is required to move the toggle linkages while under load in addition to inertia of clamp and mold. The hydraulic clamp produces a load peak of inertia to begin opening motion.

Injection Unit:

The power consumed by the injection unit can be seen in Figures Screw rotation and injection of a hydraulically driven injection unit occurs with relatively high volume and high pressure. The volume and pressure requirement is determined by the output dictated by the cycle speed, capability of the mold, plus the torque requirements of the resin being processed. Many materials process in a range similar to the test cycle of Fig. 3 and Fig. 4 , although, some more viscous materials process at higher pressures.

Fig. # 5 represents the power consumption level when a 65 gallons per minute of pumping is produced at maximum volume and varying pressure loadings. This comparison shows significant increase in power proportionate with pressure.

The vast majority of commercial injection units operate hydraulically and under similar pressure and rates. Since this function consumes the largest portion of power, it would seem reasonable that efficient circuit design would have a visible effect on overall power consumption.

Common Types of Hydraulic Circuits:

The "meter-in" or "meter-out" circuit loads the high volume fixed displacement pumps to maximum system pressure and regulates rate at this pressure into or out of the injection cylinder extruder motor, by a flow control valve. Since the pumps and the electric motors are loaded to maximum volume and maximum working pressure for the total time of screw rotation of injection, regardless of the actual rate used for the function, the power curve is peaked for this duration.

The "bleed-off" type circuit allows the system to develop only the amount of pressure needed for the job (screw rotation or injection). Control of rate is accomplished by a pressure compensated control valve "bleeding" oil to tank in excess of the rate desired for the job. If injection or screw rotation requires only moderate or low pressure the hydraulic system and electric motors are loaded only to the required pressure level rather than constantly loading pumps and motors to full pressure.

Optimization, Productivity and Versatility:

Just as feed screws can be designed for optimum processing of a particular polymer, an injection molding machine can be configured hydraulically for a specific job or type of job.

The essential goal is good basic hydraulic circuit design and sizing is accomplished, the largest source of power consumption, the electric motor and pump system remains to be sized to perform the specifications of the machine, i.e., clamp speed, tonnage, extruder RPM, torque, and injection rate. Assuming a standard machine configuration where these functions are accomplished by hydraulic pumps, the pump sizes are easily projected and the corresponding electric motor sizes are directly calculated by well-known industry standards. The equation

$$HP = GPM \times P \times K$$

HP = Maximum Horsepower required for system pressure
P = System Pressure
GPM = Hydraulic pumping rate of system
K = Constant

represents a common industry standard relation. Electric motors used for injection molding machines are typically capable of handling the short duration higher loads that occur during clamp functions, however, if motors are not sized properly for general system pressure and flow, overheating and reduced life results. Since motors consume electricity proportionately to the load placed upon them, even if overloaded, power is not saved by undersizing the motor. See Fig. 6.

Optimization

The specific injection molding job defines the actual machine capabilities required. These specifications ultimately determine the horsepower rating. From these premises it can be seen that a machine's specifications can be optimized for a specific job. Machines of the same clamp tonnage can be powered by a choice of motor pump systems to accomplish differing tasks, especially tasks which require variations of injection and extrusion functions.

Productivity

The productivity of a mold can be limited by a machine's insufficient capabilities and corresponding insufficient motor pump system. Ideally a machine's capability should be sufficient to open and close the mold as fast as part removal allows, inject as fast as part quality allows and recover or plasticize the shot size within the cooling time of the mold. Machine under-capacity does not provide maximum productivity. Excess machine specifications produce inefficient use of electrical power.

Versatility

When job requirements are variable, machine specifications must be capable of handling the most demanding job. For the lesser jobs, energy utilization may not be most efficient, but versatility is required and is paid for by initial machine capital cost plus some inefficiency of the corresponding power system versus job requirements. The molder should consider all jobs to be run and optimize machinery selection and corresponding horsepower.

Methods of Increasing Electrical Efficiency:

There are several methods of improving electrical efficiency of a machine. Each will be found to provide improvement but will also demand a price for this improvement. The price may be an increase in initial cost of a more efficient component, a higher cost of maintenance, cost of additional power saving devices, the price may also be a reduction in the maximum available capability of a given tonnage rated machine or the versatility of its operation.

Higher Efficiency Electric Motors

Electric motor manufacturers are developing higher efficiency motors which incorporate efficient metallurgy, winding and controls. These motors are sure to increase efficiency at the expense of increased initial cost.

Reduction of the Electric Motor-Pump System

When high rates and high pressures are not required of the injection unit and if the high clamp speeds are not necessary or desired, the pump sizes of a given tonnage injection molding machine can be reduced thus reducing the horsepower and power consumption.

Maximum Utilization of Pumps and Motors

If pumps are always being loaded and doing productive work they are being used most efficiently. A divert system can be incorporated to utilize the same large volume pumps for clamp functions and injection functions. This is more efficient than idle pumps that are dedicated to one function only. The price paid is the lack of versatility to run clamp and injection functions simultaneously, which may be required for maximum productivity.

Variable Displacement Pumping

These are pumps which load to a desired pressure but pump only the volume required to attain that pressure. Thus they load the electric motor only the amount actually being demanded. Most common fixed displacement pumps are constant displacement devices which, at minimum, pump their volume at low pressure to the reservoir and when called upon, load to a desired pressure to do work. (See paragraph on "Common Types of Hydraulic Circuits".) The energy efficiency of variable displacement pumping is highly desirable, but pump complexity, higher initial cost, and higher maintenance, plus a limitation of pumping capacity of commercially available units, have restricted their use. The application of small variable pumps for such applications as holding tonnage offer the potentials for their hybrid use with fixed displacement vane pumps, correctly sized for production needs. More efficient use during the cooling portion of a cycle, when only pressure, not volume, is needed to hold tonnage or hold a toggle linkage in position, is then possible. Energy savings of several percent have been recorded for such applications.

Auxiliary Motor-Pump Systems

An excellent method of adding versatility to a machine is to add a parallel auxiliary pumping system that can be turned on or off as required for various molding jobs. In this manner machine capacity is expanded or contracted to suit job demand and neither power consumption nor productivity must be compromised. The price paid is the initial capital investment for the "optional" system.

Accumulator Systems

Hydraulic accumulators are sometimes useful for conserving energy consumption when the application is appropriate. They are most often used for the injection function. Accumulators are hydraulic storage cylinders which act as capacitors, being charged by small pumps, while other functions, such as clamp opening closing and cooling, are taking place via larger pumps. Injection is accomplished by discharging the accumulator oil into the injection ram cylinder(s) in place of a high volume pump. Power is conserved by efficient pump and motor utilization. Sufficient pumping to accomplish plastication within cycle must accompany accumulator systems to attain full benefit of their use, since accumulator oil is not normally used for screw rotation. Injection rate is not as easily controlled, as pressure changes during discharge of the accumulator. If controlled packing is desired a parallel pump system is desirable.

Regenerative Circuits

A regenerative circuit can be used to increase the forward speed of a cylinder without increasing pumping requirements. Oil from the rod end is connected to the larger piston end of the cylinder. This oil adds to the flow pumped to the larger piston end during forward stroke increasing its speed. The force of the piston is, however, reduced, and the resulting forward force is equal to hydraulic pressure multiplied by the rod area which is the differential area pressured by the oil. The return speed and force is not changed and operates conventionally.

These circuits are most often used for part ejector cylinders or core and mold cylinders when large forces are not required for a specific job or job type. The reduction in force is generally too large to apply this circuit to injection since rate of injection is a function of both pressure (force) and rate (flow).

Power Factor Capacitors

Power factor capacitors are devices which alter the ratio of actual to apparent power in an inductive load such as an AC motor where current inefficiently leads voltage. Power factor capacitors compensate for this poor phase relationship and bring the ratio closer to unity. The electric motor does not become more efficient but rather consumes power from the utility generator more efficiently. These power factors are an external device to the injection molding machine which makes its operation less expensive. Payback time for these devices is most often less than a year.

Vented Barrel

Vented injection units enable the elimination of a dryer system for drying hygroscopic resins. A slightly longer barrel is necessary with resulting additional heater bands but this is more than offset by power normally consumed by the dryer. Capital investment differences and maintenance differences are other cost items of consideration.

Insulated Heater Bands

Heater bands which incorporate an outer insulation to prevent heat convection to surrounding air and maximize electrical efficiency are commercially available. Manufacturers tests have shown sample power savings of 50% over mica type bands and 30% over standard ceramic bands. Additional potential benefits are improvement of plant environmental control.

360° Surround Barrel Shields

Barrel shields which completely surround the injection barrel, prevent the loss of heat by convection. Some polymers which internally generate considerable heat by shear and friction may cause overheating problems because of inability to convect heat away from the barrel. A shield which has a hinged section for opening can correct this condition.

Screw Design

Each polymer desires a specific mix of external conductive heat from the injection barrel and internally induced frictional shear heat produced by the compression and mixing of the feed screw. The most efficient screw provides the best melt and thus the highest quality moldings and accomplishes this by a good balance of heat input. Screw design that enhances mixing also improves heat input and melting. For general purpose molding of many different polymers this optimization of screw design is often compromised.

Heater Bandless Nozzles

This nozzle incorporates small heat pipes which draw heat from the injection barrel. Energy that is saved is the additional radiant heat that would be lost if an external heater band was used on a standard nozzle. This is certainly not a large savings and greatest benefit results from elimination of heater band maintenance.

Watt Meter

The installation of an instantaneous reading watt meter enables setup personnel to minimize power usage by observing the meter reading as pressures and rates are set for a specific mold. Minimum energy consuming settings can be made that yet yield the desired production requirements. Excessive rate or pressure, which directly relate to wasted horsepower are thus prevented.

An Energy Comparison:

To qualify all of the energy saving methods a special machine was configured and is displayed at the 1979 National Plastics Exposition. The mold that was tested does not call for a high injection rate or extruder pressure and rate, thus the performance of this machine was matched to the job requirements and does not waste any excess capacity. The resulting machine incorporates the following features:

High Efficiency Electric Motor
Smaller Horsepower Motor
Smaller Pump Size
Pump Divert Circuit To Utilize Only One High Volume Pump
Variable Displacement Pump For Low Volume Clamp Tonnage Holding
Regenerative Circuit For Hydraulic Ejection
Insulated Heater Bands
360° Surround Barrel Shield
Optimized Screw Design
Vented Barrel
Power Factor Capacitors
Special Heater Bandless Nozzle
Water Saver Valve
Watt Meter

Comparison Of Machine Specifications

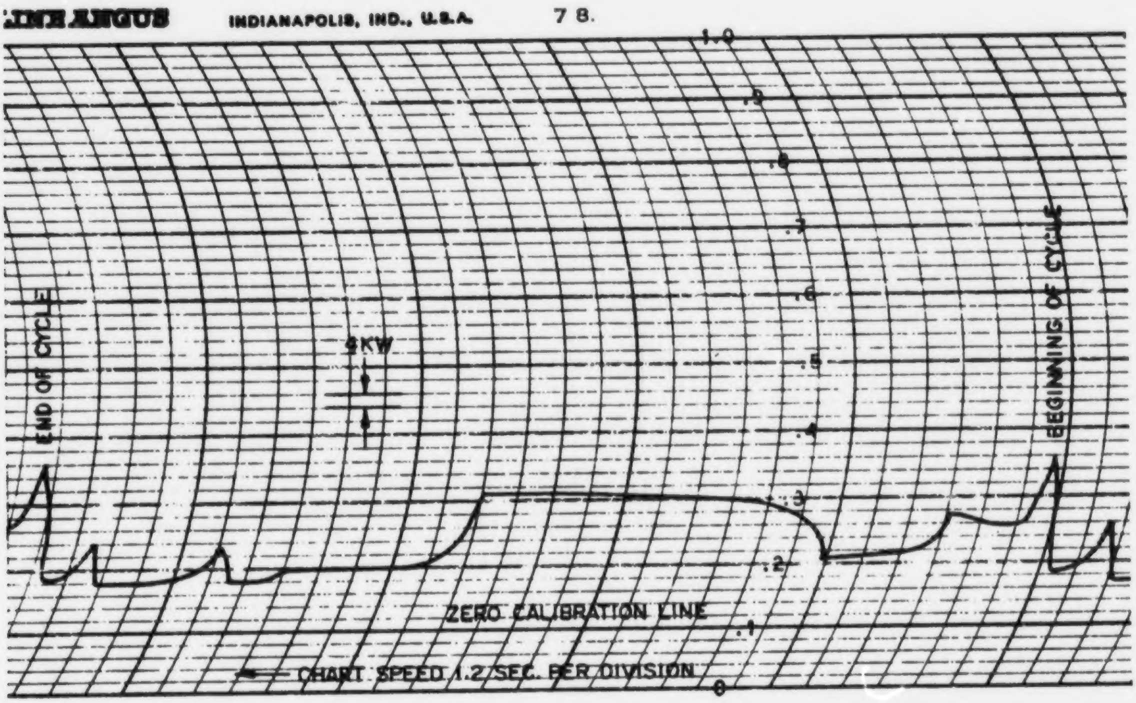
	Power Saver Machine	Standard Machine
Tonnage	250	250
Injection Capacity (oz.)	20	20
Injection Rate (maximum) (cu./in./sec.)	16.2	23.1
Maximum RPM	143	205
Clamp Speed		
Forward (in./min.)	1260	1800
Reverse (in./min.)	1015	1450
Horsepower	40	60
Total Pumping Capacity (GPM)	51	130

Cycle Data for a 10" x 12" x 1.5" ABS Refrigerator Tray.

Tonnage Requirement	250
Shot Weight	328 gm (11.6 oz.)
Melt Temperature	450^{o} F
Cooling Time	19 seconds
Injection Time High Volume	4 seconds
Packing	5 seconds
Melt Decompression	1 second
Overall Cycle Time	33 seconds

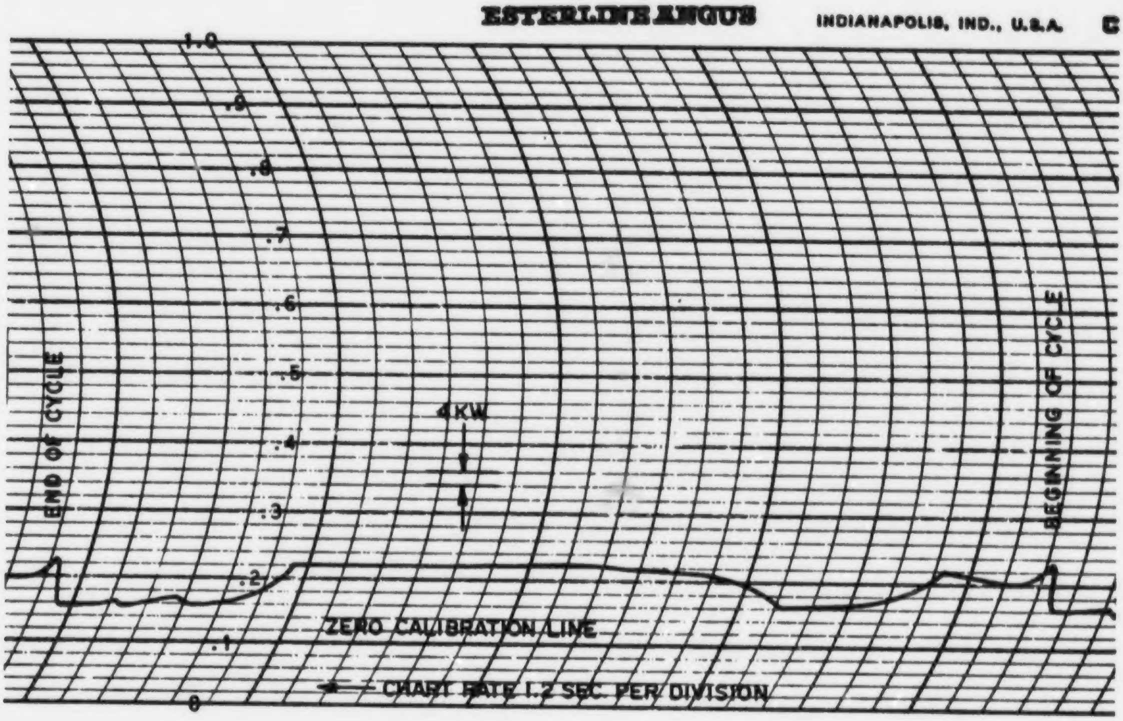
Comparison Of Power Consumption

Standard 250 Ton 20 Ounce Machine - KW usage for production cycle of ABS refrigerator tray.



Average Total Machine Power Consumption	33.3 KW
Average Dryer Power Consumption	5 KW
Total Production Power Consumption Machine plus Dryer	38.3 KW

Power Saver 250 Ton 20 Ounce With Vented Barrel - KW usage for production cycle of ABS refrigerator tray.



Average Total Machine Power Consumption 20.4 KW

Note! Resin dryer not needed.

Summary:

The machine with a vented barrel and all of the energy reducing options consumes only 20.4 KW versus 33.3 KW for a standard specification 250 ton 20 ounce machine. This represents a reduction of electrical power consumption of 38.7 percent. If the cost of running a dryer is included, power savings of 46.7 percent are realized.

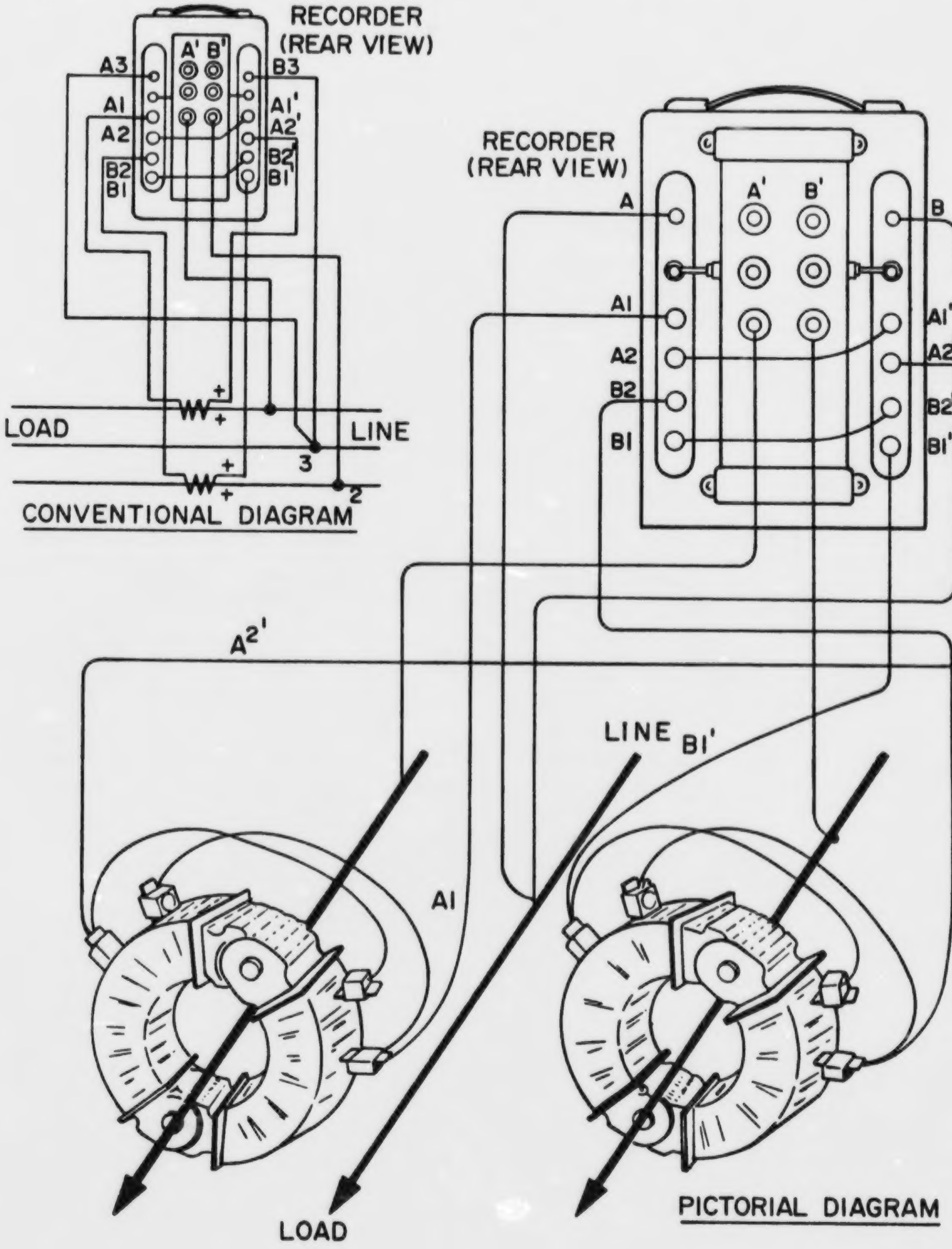
The degree to which a machine purchaser might desire to specify a machine for power saving features msut be carefully analyzed for the performance needed and for the additional cost return of items such as power factor capacitors, auxiliary pump/motor systems, and other extra initial cost and energy saving items.

The comparison test described shows the degree of savings that can result when a specific job is defined. Energy must always be weighed as a return on investment from productivity and from payback for energy saving devices and methods, with the often important consideration of flexibility and versatility taken into account.

PREPARED BY:

Frederick A. Rolls
Edward M. Zakrzewski

FIG. I SCHEMATIC OF POWER TRANSDUCER / RECORDER AND WIRING CONNECTOR



RECORDER (REAR VIEW)
A'
B'
A3
A1
A2
B2
B1
B3
A1'
A2'
B2'
B1'
LOAD
LINE
3
2
+
RECORDER (REAR VIEW)
A
B
A1
A2
B2
B1
A1'
A2'
B2'
B1'
A2'
LINE
B1'
A1
LOAD

CONVENTIONAL DIAGRAM

PICTORIAL DIAGRAM

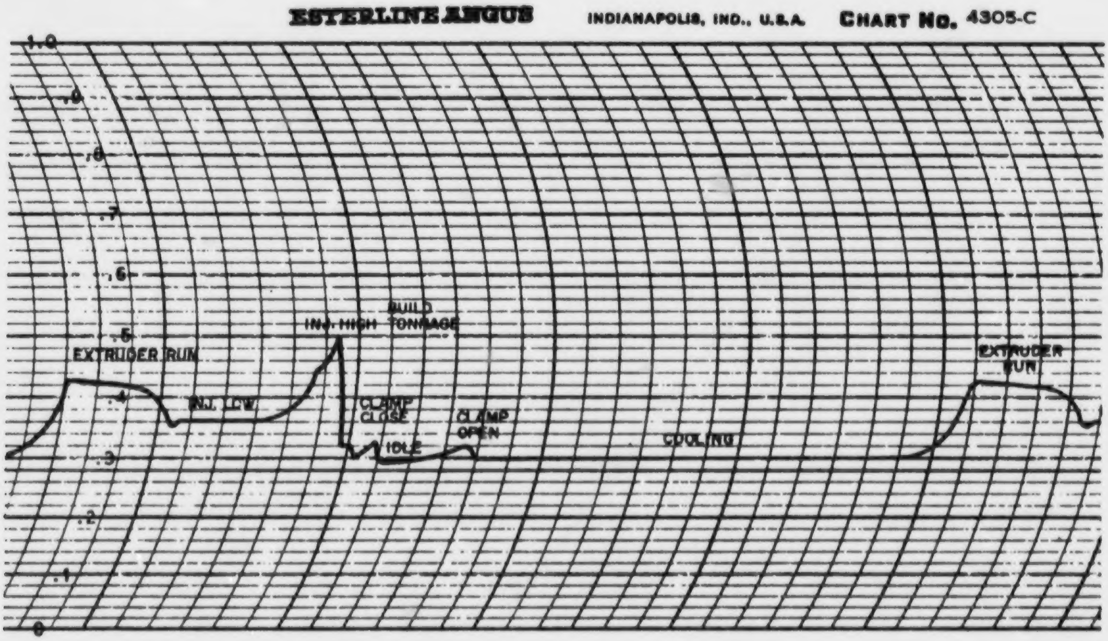


FIG. 2 EXAMPLE OF POWER USAGE VS. TIME
FOR A TYPICAL MOLDING CYCLE
(STYRENE PART – 250 TON MACHINE)

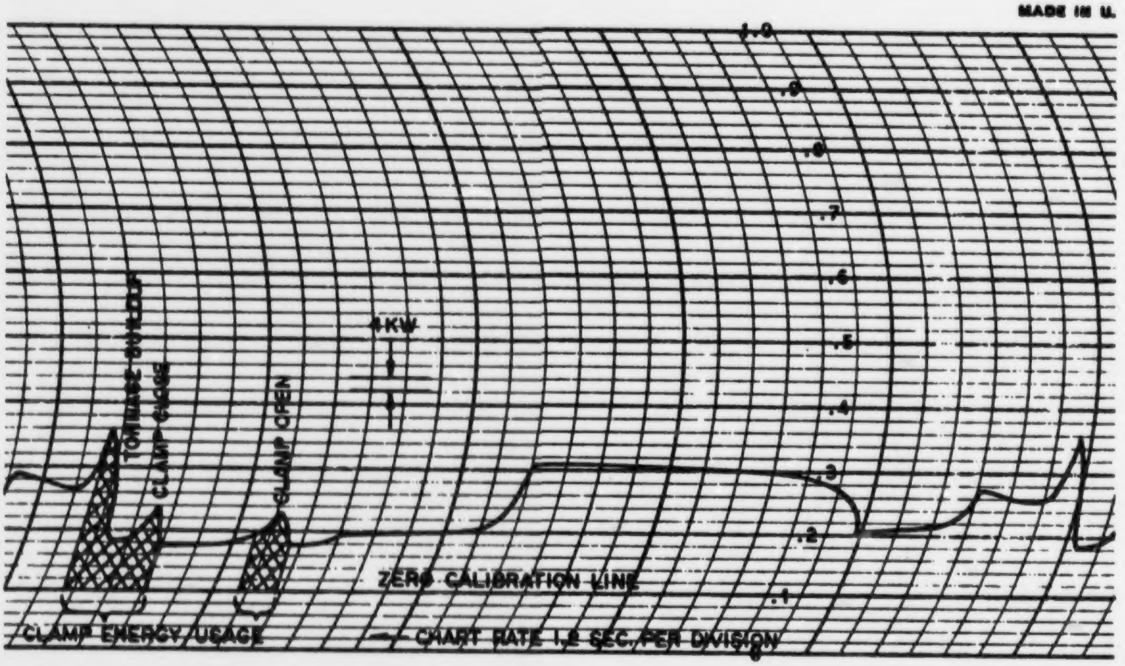


FIG. 3 RECORDING OF KILOWATTS VS. TIME
FOR A 250 TON HYDRAULIC RAM TYPE PRESS (60HP)
(ABS REFRIGERATOR TRAY CYCLE)

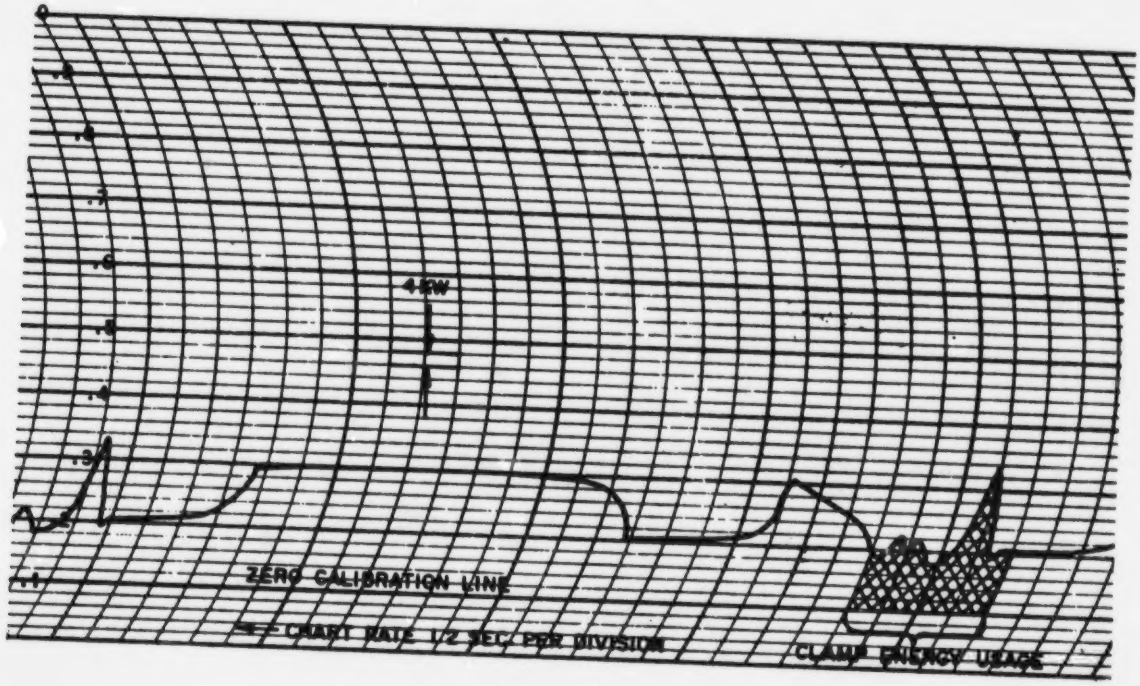


FIG. 4 RECORDING OF KILOWATTS VS. TIME
FOR A 300 TON TOGGLE TYPE PRESS (50HP)
(ABS REFRIGERATOR TRAY CYCLE)

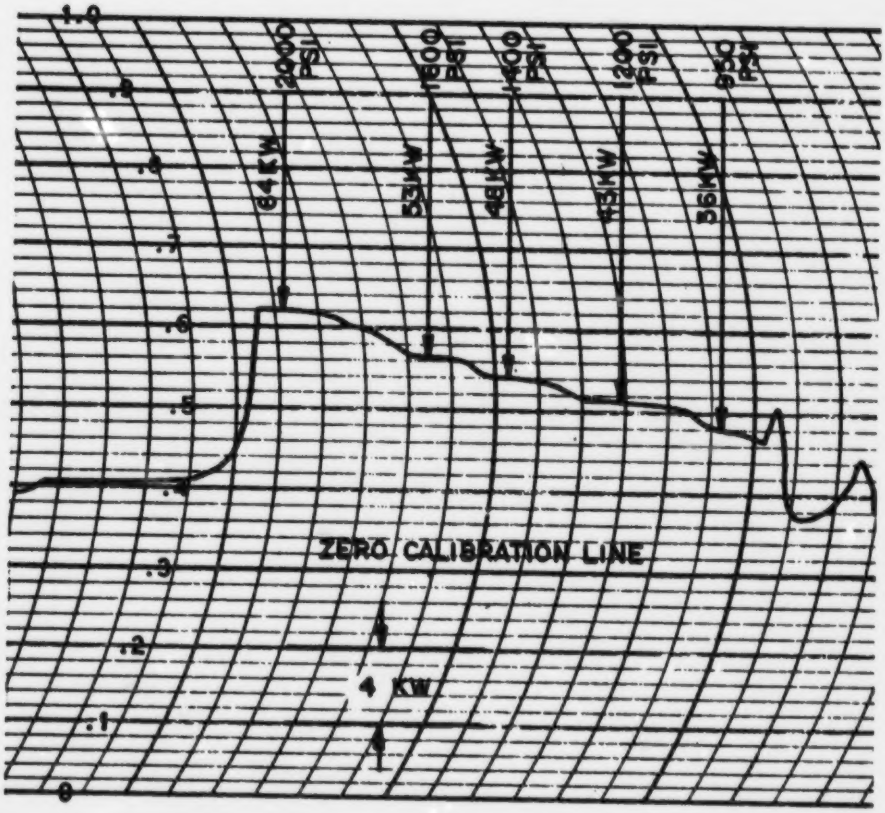


FIG. 5 RECORDING OF THE EFFECT OF PUMP PRESSURE LOADING ON KW USAGE (60 HP MOTOR @ 65 GPM PUMP RATE)

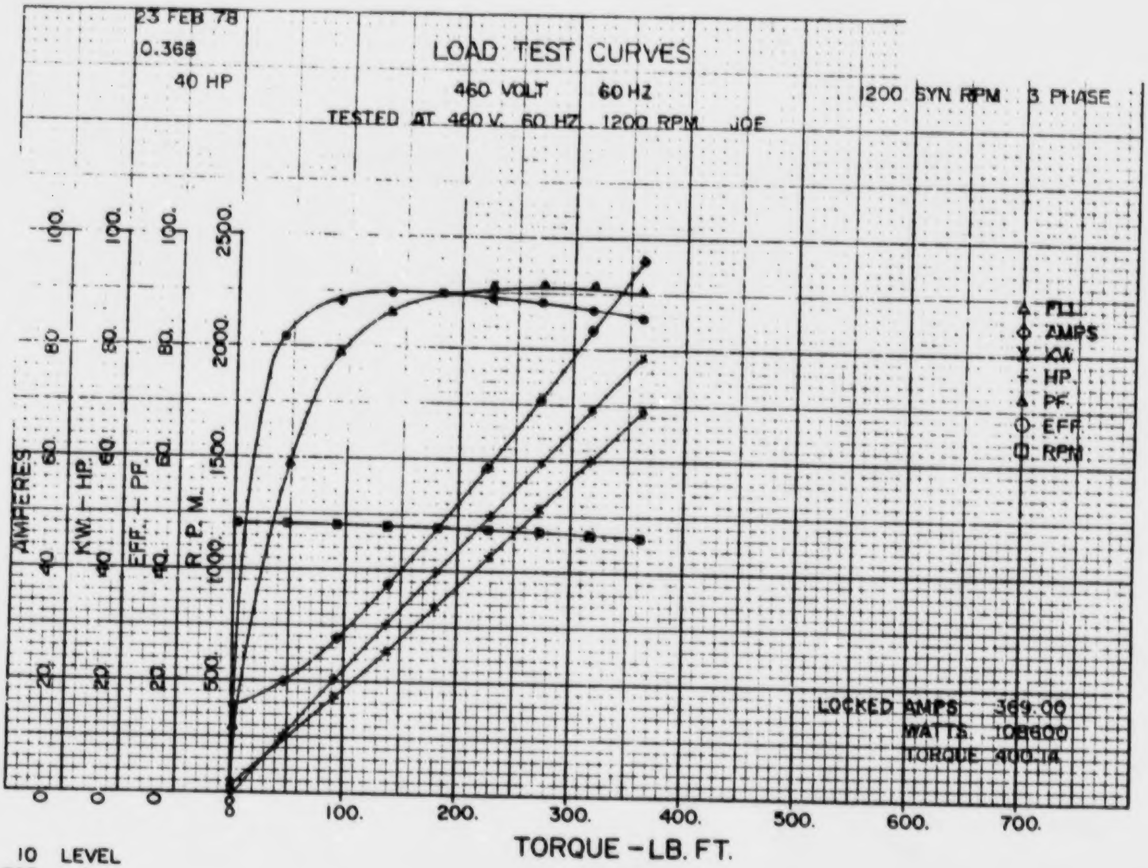
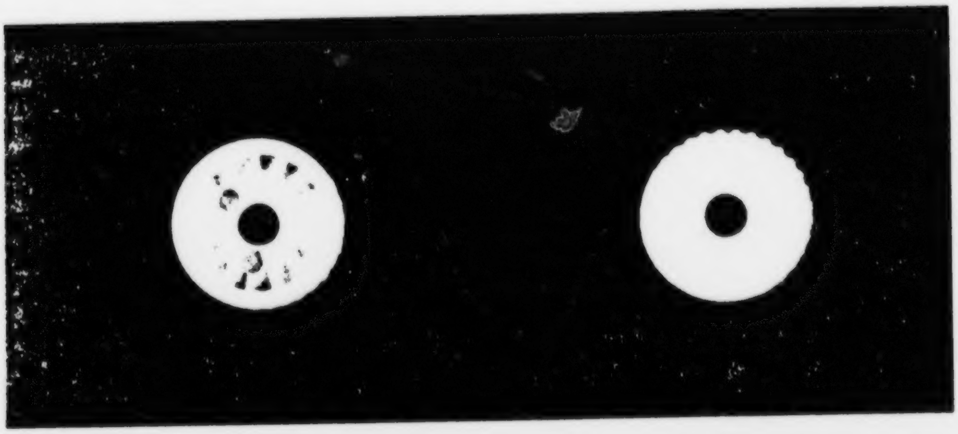

23 FEB 78
10.368
40 HP
LOAD TEST CURVES
460 VOLT
60 HZ
1200 SYN RPM
3 PHASE
TESTED AT 460 V. 60 HZ 1200 RPM. JOE
FLL
AMPS
KW
HP
PF
EFF
RPM
AMPERES
KW. - HP.
EFF. - PF.
R. P. M.
0
20.
40
60.
80
100.
500.
1000.
1500.
2000.
2500.
100.
200.
300.
400.
500.
600.
700.
LOCKED AMPS 369.00
WATTS 108600
TORQUE 400.1A
TORQUE - LB. FT.
10 LEVEL
866 1

FIGURE 6

Now, power consumption in actual molding is compared with that of conventional molding machines in some examples. What is important here is under what conditions the conventional machine is compared. It is well known that machines even of the same performance specifications show considerable ups and downs in power consumption in each cycle depending on the operating conditions. If a machine is operated at the fastest possible speed without slowing down the mold opening, closing and injection speeds, the power loss in the particular step is nearly nothing and when compared with the operation at one half the speed, the power saving must have been over 50%. As described before, the power saving rate varies over a wide range according to the kind of molded product, molding material, molding conditions and mold constructions. And through numerous tests, we found out that the power saving rate is in the range from 30% to 70%. In Table 1 to 3 are introduced some typical examples. Since the power saving rate of heat insulating heater covers falls short of the power saving rate obtained by the hydraulic drive system, the overall power saving rate is slightly lower.

In Table 1 are shown the molding conditions adopted when molding a polyacetal gear and in Fig.6 are the records of instantaneous power (only for the pump motor) in a cycle of both the conventional machine and SSE machine. (1) The mold closing speed is fairly fast and as a result there is little difference in power. (2) The secondary injection pressure was set at 16 kg.f/cm² (gauge pressure). As the screw does not move nearly at all during the secondary pressure, no pump discharge was necessary. Yet there was a considerable difference as pressure was needed. Generally speaking, molding of thick wall lens and similar items needs a longer time for the secondary pressure, therefore, the difference in this step will be considerably large. (3) The screw speed was set at 90 rpm. The conventional machine was equipped with the pressure match system only for the screw driving oil motor circuit, yet it could not match the SSE machine and there resulted a slight difference. (4) The mold was a 3-plate type which opens the runner plate by means of a link. The mold opening speed was medium and the slow-down distance had to be set for a slightly longer distance than in normal operation. Accordingly, there resulted a great difference as shown in the drawing. (5) The knock-out cylinder is smaller than other actuators and it was not intended since early days to actuate it at the highest flow rate. Here, we used a switch valve and throttle valve with the capacity smaller by one ranking. So, there resulted a great difference even when the throttle valve was full open.

From these results, it was found that power consumption per cycle by the conventional machine was 69 Wh, by SSE machine 40 Wh and the power saving rate 42%.



Molded parts		Precision gear
Molding material		Polyacetal (Duracon M-90)
Product weight		42 g
Number of mold cavity		16
Gate system		Pinpoint
Molding conditions	Injection time sec	2.0
	Cooling time sec	8.5
	One cycle sec	16.0
	Injection pressure (gauge)	Primary 104, Secondary 31
Temperature	Heating cylinder, front ℃	190
	central ℃	180
	rear ℃	160
	Nozzle ℃ (V)	200
Power saving rate (per shot) (Hydraulic motor)		46.2%
Total power saving rate (per shot) (including cylinder heaters)		15.4%

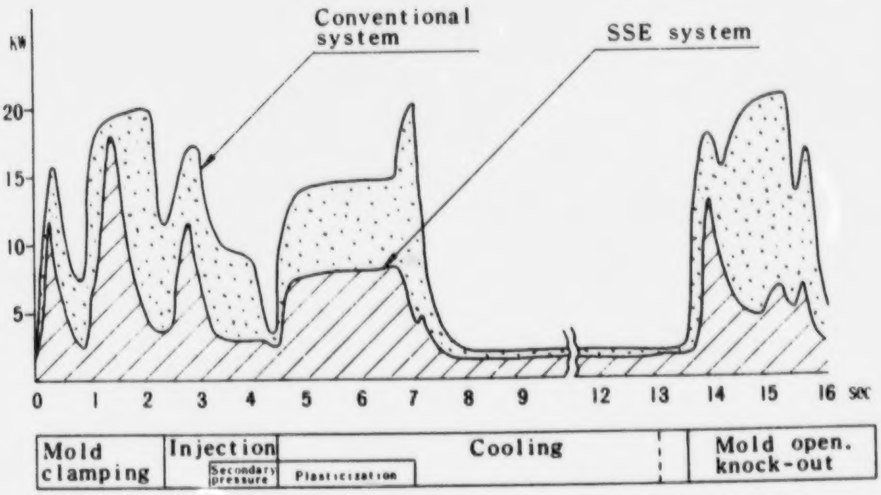


Fig.6 Comparison of Power Consumption by System
(One Cycle only for motor)

ENERGY SAVING INJECTION MOLDING MACHINE SSE SYSTEM

Key Points for Energy Saving

Energy saving may be synonymous with higher efficiency. Since an injection molding machine is operated by electric power, the higher efficiency means how best this electric power can be led to production effectively. It is to raise the effective power consumption ratio in the total power consumption. Since most of the reactive power or power loss is consumed in the form of energy for heat or sound, it is important, when higher efficiency is in mind, to find out what are the major sources of heat or sound in a machine and to control them to the lowest possible level.

1. Real Mechanical Efficiency

For injection molding machines, the real mechanical efficiency seldom makes a problem as they have less number of power transmitting mechanical parts as compared with those in other machines, machine tools or textile machines. The mold clamping unit performs a simple reciprocating motion and the injection unit has only the revolving motion added to the reciprocating motion. Conceivable losses are, for instance, the sliding frictional loss at each cylinder and packing, frictional loss between the movable mold platen and tie bar and frictional loss at the spline section at the time of screw driving, but they are not so large. Some say the toggle system may be advantageous over the direct pressure system, but they are confusedly discussing the mechanism and hydraulic circuit here. When real mechanical efficiency is considered, these two are nearly equal or the toggle system is slightly disadvantageous for such a reason that the vector of force in the toggle pin at mold opening and closing does not constantly face the opening and closing direction.

2. Efficiency of Hydraulic Drive Unit

The hydraulic unit has such components as a hydraulic pump, pump motor, control valves, hydraulic actuator, pipings and hydraulic oil. Efficiency of individual component determines the efficiency of a system, therefore, it is important to select a pump actuator of high volume efficiency, control valves of less pressure loss, pipe size and piping works with less pressure loss and the use of hydraulic oil with its viscosity not too high.

3. Efficiency of Hydraulic Circuits

Even if each component of the hydraulic drive unit has high efficiency, the effect may be still dropped to a half if the efficiency of hydraulic circuits which make up the whole system is not taken into consideration. Generally speaking, a circuit may as well be the simplest possible one and it is necessary to avoid many control valves connected in series in between the pump and actuator. Moreover, what drop the efficiency sharply in the conventional circuits are the following two. First, if the flow rate is regulated by the flow control valve to regulate the actuator speed, the surplus oil discharged from the pump will push open the pressure control valve (relief valve) and return to the tank while generating heat. Here, if the pressure needed by the actuator is equal to the pressure set on the pressure control valve, the loss may be a little. But if the necessary pressure is lower, the loss will be great. Secondly, when the actuator reaches the stroke end and only a constant pressure is needed, the all oil will push open the relief valve and return to the tank even though the pump discharge is not necessary nearly at all. Holding of the mold clamping pressure is exactly at this state and from the standpoint of power consumption, there will be a debate over the advantage and disadvantage between the toggle and direct pressure systems. A direct pressure system may perform equally well as a toggle system if the hydraulic circuit is so modified. In other words, as the pressure inside the cylinder reaches the predetermined level, the check valve is actuated, and then in the injection stage, it is intended to hold the mold clamping pressure without relying on the supplemental discharge by the pump. Naturally there will be no power loss. Our FS machines have adopted this system in early days.

4. Thermal Efficiency of Heaters

The screw cylinder of an injection molding machine for thermoplastic materials is heated and the temperature is controlled by heaters. To increase thermal efficiency, the only way is to release no heat to atmosphere. Heater covers in the past were designed for safety and heat stability, but now the heat insulating function has been added to increase the efficiency.

5. Efficiency of Electric Control Circuits

Electric control circuits also consume some electricity, but the percentage is small to the entire power consumption of a machine. The coil section of a solenoid valve may be hot sometimes and this heat is all released into the oil or atmospheric air as energy loss.

Now, the foregoing has made a general review of each component from the standpoint of efficiency. Then, how electricity is supplied and how it is consumed were investigated to find out that in the power supply capacity (power rating) of a general purpose machine, an average 70% was for the pump motor and 30% for heaters. Further, in a molding operation which is thought to be a typical one, power consumption by each step is as shown in Fig. 1. Judging from this example, the actual power consumption by the pump motor is 86% and by heaters 14%. These indicate how important the efficiency increase of the hydraulic drive system is when energy saving or higher efficiency is considered for any machine.

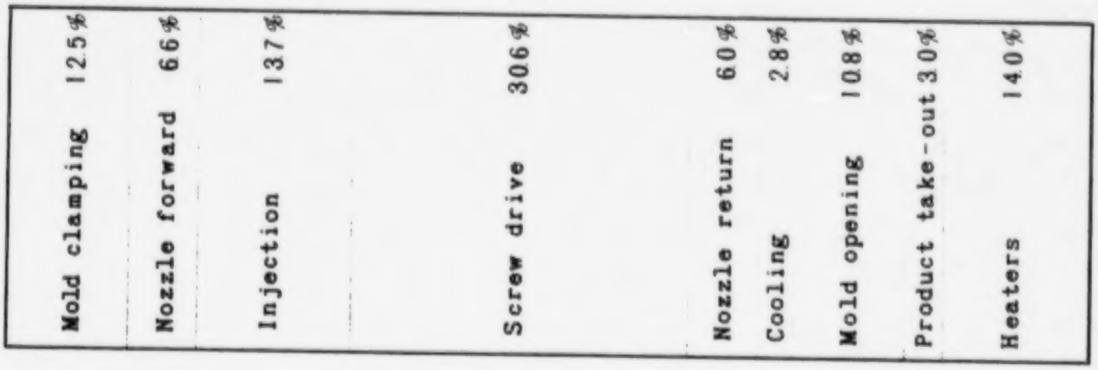


Fig.1 Percentage of Power Consumption by Each Step

Efficiency Comparison of Hydraulic Drive System

In a hydraulic system, if power is L(KW), pressure P(kg.f/㎠) and flow rate Q(ℓ/min), a relationship of $L \fallingdotseq \frac{P.Q}{612}$ will be established. As power is proportional to the product of pressure and flow rate, L can be shown as a rectangular area with sides as P and Q, respectively. Based on this concept, here is reviewed the efficiency of hydraulic systems.

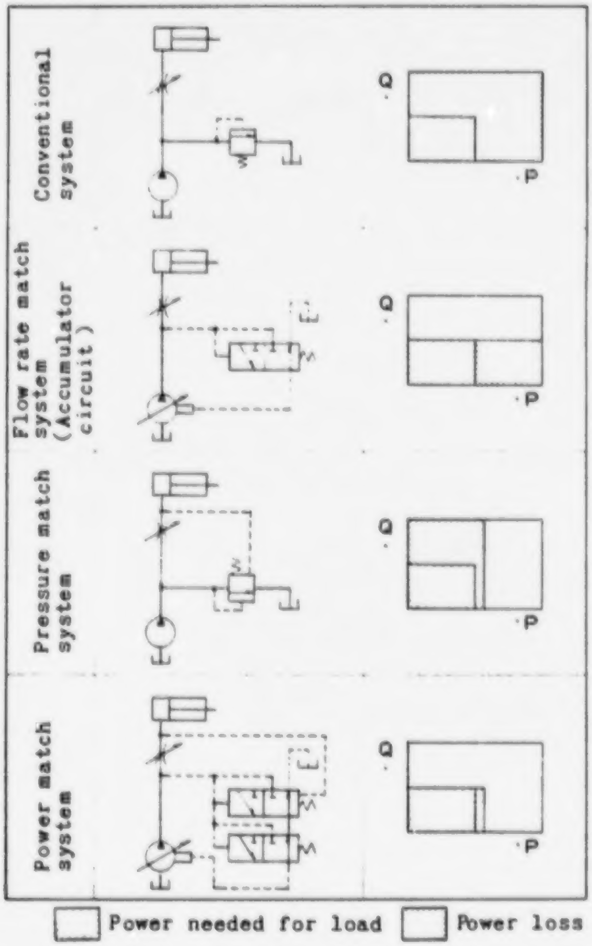


Fig.2 Power Characteristics of System

In Fig.2 are illustrated hydraulic circuits and power characteristics of four typical hydraulic drive systems in diagrams. For each case shown here, it is assumed that to the highest possible performance (the highest possible pressure and flow rate that can be developed by the pump), the pressure and flow rate actually needed by the actuator were half the level. To be more practical, take a screw driving oil motor for example, such a case is assumed that the pump pressure may be raised to 110 kg.f/㎠, but the resin viscosity at the time is not so high, therefore, the motor is driven at 70 kg.f/ and, furthermore the maximum speed of 200 rpm is possible, but it was driven at 100 rpm due to the molding conditions.

1. Conventional System

This is a combination of a constant discharge pump and relief valve. This has one actuator and the system is perfectly well when the load pressure and speed are constant and the speed needs the entire volume of pump discharge. However, there are at least several actuators on an injection molding machine and each one of them has a different capacity. Moreover, depending on the molding conditions, the load pressure and speed need a considerably wide adjustment range, and this will often result in a great power loss as shown in the drawing.

2. Flow Rate Match System

This is a combination of a variable pump and discharge regulating valve. No loss in flow rate, but the pumping pressure rises to the highest setting despite of a low load pressure. In other words, the power loss will be equal to the product of the pressure difference between the highest setting and service pressure and the flow rate in service. The accumulator circuit is a combination of a constant discharge pump and accumulator. however, from the standpoint of power characteristics, this is similar to the flow rate match system and there results a power loss equivalent to the product of the pressure difference between the pressure held and pressure in service and the flow rate in service.

3. Pressure Match System

This is a combination of a constant discharge pump and differential pressure type relief valve. Nearly no pressure loss, but there results power loss equivalent to the product of the volume difference between the pump discharge and flow rate in service and the pressure in service.

4. Power Match System

This is a trinity of a variable pump, discharge control valve and discharge pressure control valve, which exhibits combined effects of the flow rate match system and pressure match system. Nearly no power loss, but a slight pressure loss for pressure compensation, so it is an ideal system for injection molding machines which must control several actuators, large and small, over a considerable range.

Machine With SSE System

The foregoing has described efficiency of various factors needed for desighning an energy saving machine. A review over the hydraulic circuits adopted for the injection molding machines now available on markets indicates that most of them are built with the conventional systems above mentioned and some machines adopt the flow rate match or pressure match system. Our molding machines have also adopted the flow rate match or pressure match system since early days, however, results, looking from the standpoint of power saving, have never been satisfactory.

Based on such results, we set our target on the highest efficiency …… that is, under any molding conditions, hydraulic oil and pressure are supplied only as needed for the movements of each cylinder and oil motor …… in other words a system that consumes only the necessary amount of electric power. And we continued our studies on a power match system adaptable for injection molding machines and also suitable hydraulic circuits and power control system until we completed SSE(Super Save Energy) system which has realized stable and precision molding. In Fig. 3 is shown the block diagram of this system.

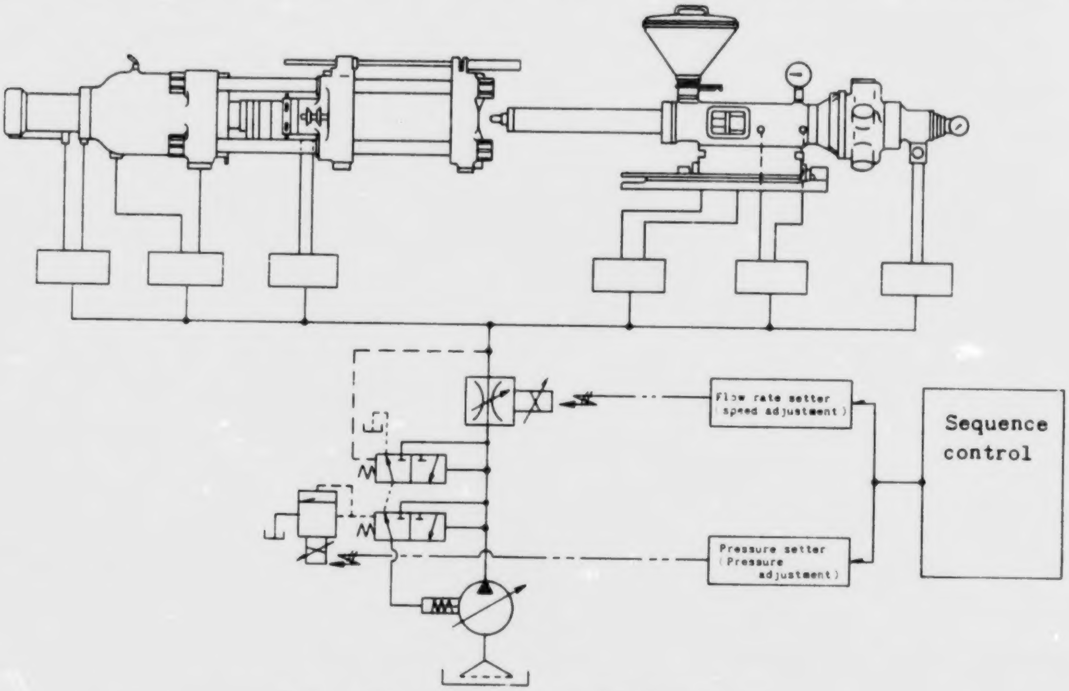
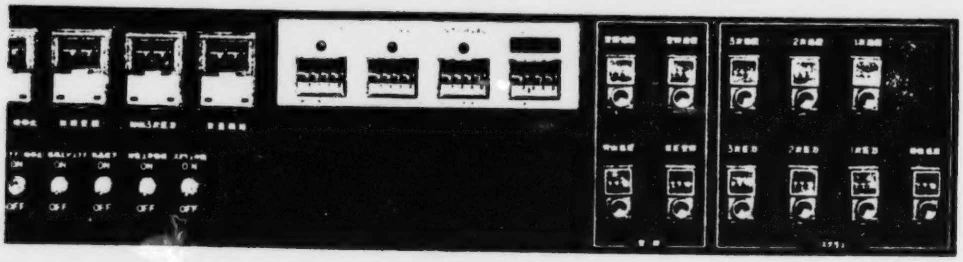


Fig.3 Block Diagram of SSE System

The setters shown in the block diagram of SSE System adopt a digital system, which not only improves operation convenience, but also contributes to a better repeatability of settings.

Further, this SSE System has both the single pump system and multi-pump system, so that it can be adopted for medium and large size machines.



1. Operation of Power Match System in Brief

Shown in Fig. 4 is the explanatory drawing of operation of the power match system. The variable pump in the drawing indicates that it works to deliver a small volume when the pressure of the pilot line 3 is high and a large volume when it is low. The pumping pressure is led to the left end of the spool A and if the flow rate is too high for the setting on the flow control valve, the difference between the pumping pressure and load pressure becomes larger than the set difference of pressure (determined by the spring B), therefore, the spool A is pushed to the right to connect the passage 2 with the pilot line 3. As this raises the pressure of the pilot line 3, the discharge volume of pump is decreased. On the contrary, if the flow rate is lower than the setting, the spool A is pushed to the left, thus connecting the pilot line 3 and tank line to increase the flow rate. By repeating such motions in a series, the flow rate of the pump will be adjusted to the setting and the pressure difference between the pumping pressure and load pressure will be adjusted to the value set by the spring B.

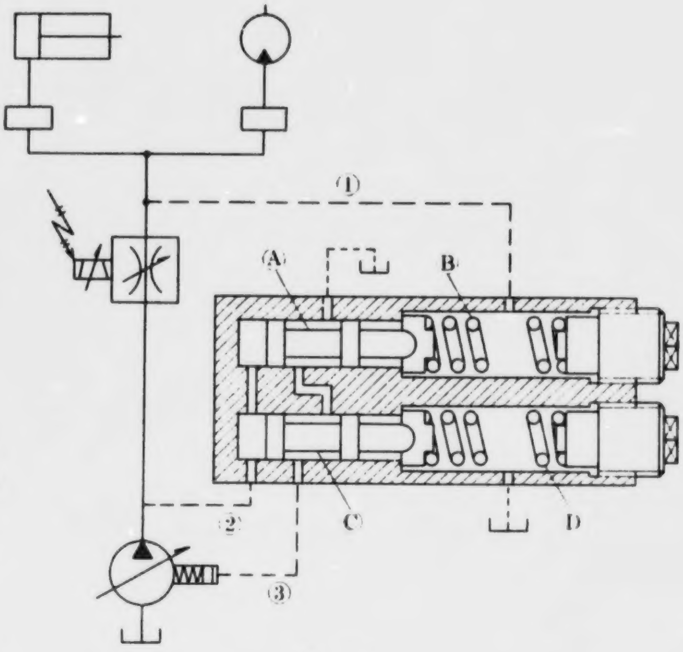


Fig.4

Meanwhile, the pumping pressure is also led to the left end of the spool C, which is pushed to the right if the pumping pressure goes over the value set by the spring D and by connecting the passage 2 and pilot line 3, it reduces the flow rate……a cut-off state. If the setting of flow rate is 0 (zero), the pressure of passage 1 is 0 (zero), therefore, the spool A is pushed to the right. And this will connect the passage 2 and pilot line 3 and bring the pump discharge to nearly 0 (zero).

2. Effects of Machine with SSE System

This SSE System employs a variable pump and, for this reason the problems inherent with the pump are naturally pointed out, i. e., 1) response, 2) noise and 3) surging pressure. However, in this SSE System, these have all been eased. In Fig. 5 are shown the speed and pressure curves when the injection speed is changed in many steps. There, as the pressure rises at the forward limit of injection, the surging pressure is nearly negligible. The operating noise has been reduced to the level of conventional general purpose machines.

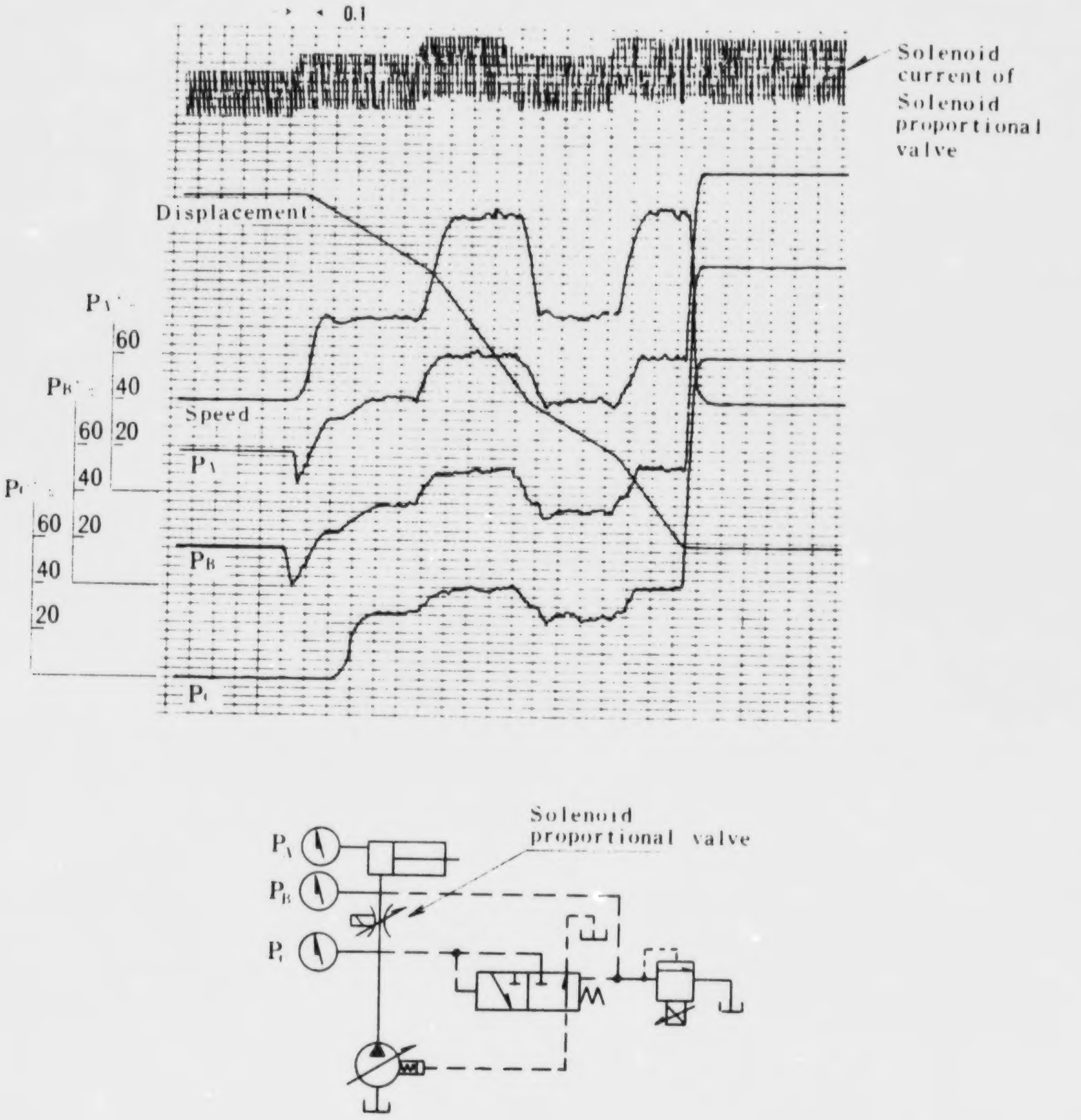
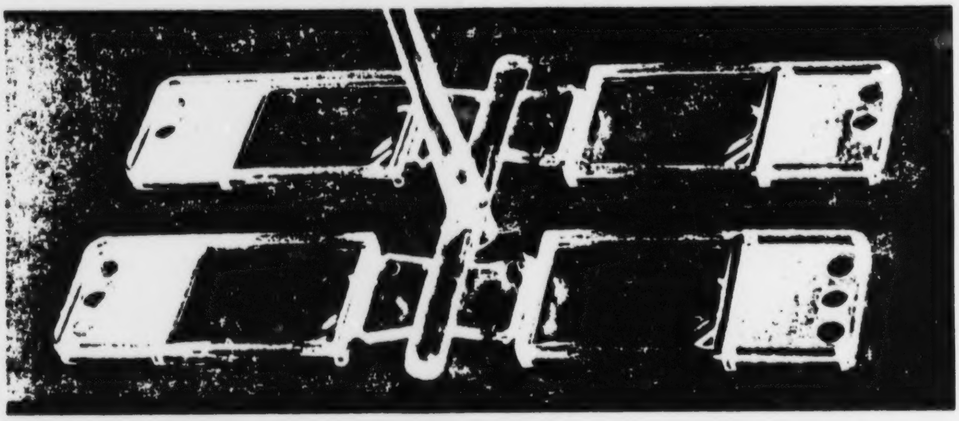


Fig.5 Injection Speed and Pressure Curves

In Fig. 7 and Table 2 are shown the molding conditions for a squre convex lens and instantaneous power in a cycle. When injection time, particularly the pressure holding time is long, the power saving effect is so remarkable as such.

Table 2 Molding of Thick-walled Parts with Long Cycle Time (Square convex lens)



Molded parts		Square convex lens
Molding material		Acrylic (Acrypet V)
Product weight		52 g
Number of mold cavity		4
Gate system		Fan gate
Molding conditions	Injection time sec	30
	Cooling time sec	35
	One cycle sec	74
	Injection pressure (gauge)	Secondary pressure 63
Temperature	Heating cylinder, front ℃	230
	central ℃	225
	rear ℃	200
	Nozzle ℃(V)	230
Power saving rate (per shot) (Hydraulic motor)		70.8 %
Total power saving rate (per shot) (Including cylinder heaters)		63.6 %

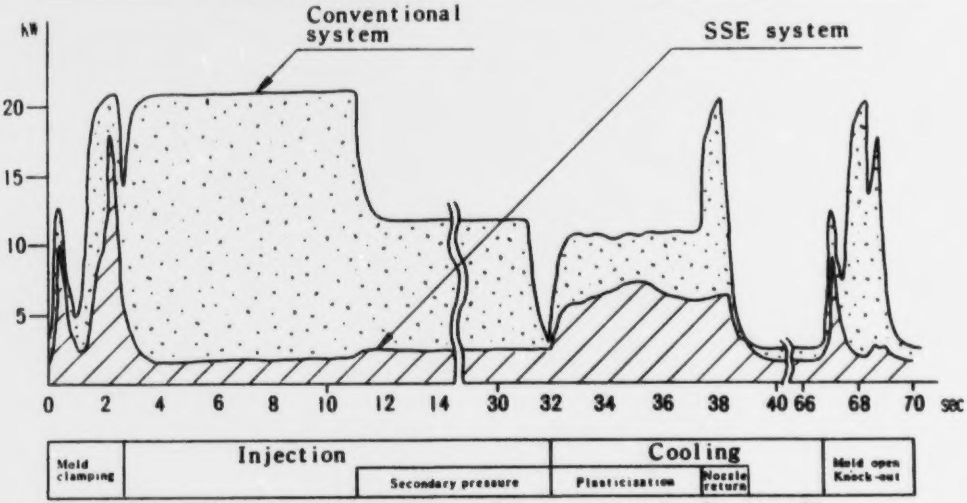
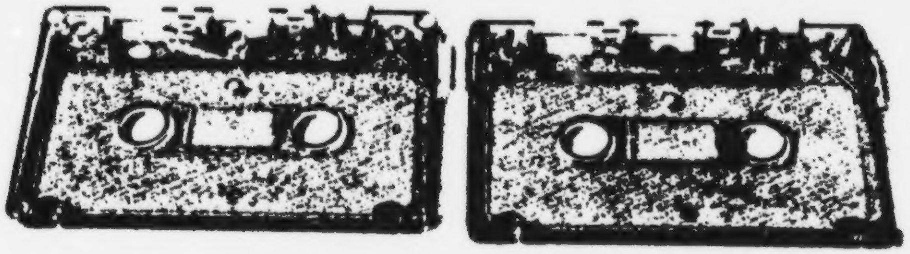


Fig. 7 Comparison of Power Consumption by System II
(One Cycle, only for motor)

In Fig. 8 and Table 3 are shown the molding conditions for a half cassette and instantaneous power in a cycle. This is a typical case for a short injection time, short pressure holding time and other movement at the highest speed.



Molded parts		Half cassette
Molding material		AS (Litac A)
Product weight		46 g
Number of mold cavity		4 (two sets)
Gate system		Hot runner (Spear System)
Molding conditions	Injection time sec	2 0
	Cooling time sec	3 0
	One cycle sec	9 5
	Injection pressure (gauge)	Secondary pressure 90
Temperature	Heating cylinder, front ℃	230
	central ℃	230
	rear ℃	210
	Nozzle ℃ (V)	220
Power saving rate (per shot) (Hydraulic motor)		31.0 %
Total power saving rate (per shot) (Including cylinder heaters)		31.4 %

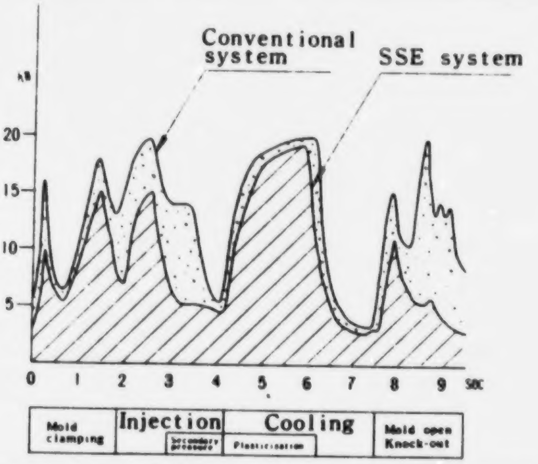


Fig. 8 Comparison of Power Consumptior by System III (One Cycle, only for motor)

Reducing energy consumption in injection moulding machines

by A V Chivers*

The steady escalation in the cost of energy in all its forms has forced designers of injection machines to become increasingly innovative, particularly with regard to hydraulic circuitry.

The last few years have seen a rapidly escalating cost for energy in all its forms. This has caused increasing concern among users of injection moulding machinery about the efficiency of their machines.

A modern injection moulding machine consumes electrical energy in three main areas:

- Control system (Q_c)
- Electric motor/hydraulic pump drive system (Q_m)
- Barrel heating system (Q_h)

This gives the equation for total electrical energy consumed to:

$(Q_t)==Q_c+Q_m=Q_h$

A control system normally consumes no more than 2% of the total energy consumption of the machine and is therefore omitted. This reduces the above energy equation to:

$Q_t = Q_M + Q_H$

For a typical, large injection moulding machine the total installed power of the machine would be 200kW comprising 150kW for the electric motors and 50kW for the barrel heating system. However, it must be borne in mind that, although the barrel heating system has an installed power rating of 50kW, when the machine is at its correct operating temperature the energy consumption is minimal, only needing to be sufficient to maintain the required temperatures on the barrel. Also, when processing certain polymers the shear heat generated by the screw is sufficient to maintain the required temperature, so causing the temperature controllers to switch certain zones off completely.

As machines have become faster and installed horse power has become lower, the time has come where the law of conservation of energy has taken over and there are now machines on the market where the installed screw torque in kW almost equals the installed horse power. Therefore, it is important that, when comparing machines, a

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Energy consumption graph for a typical injection moulding machine cycle

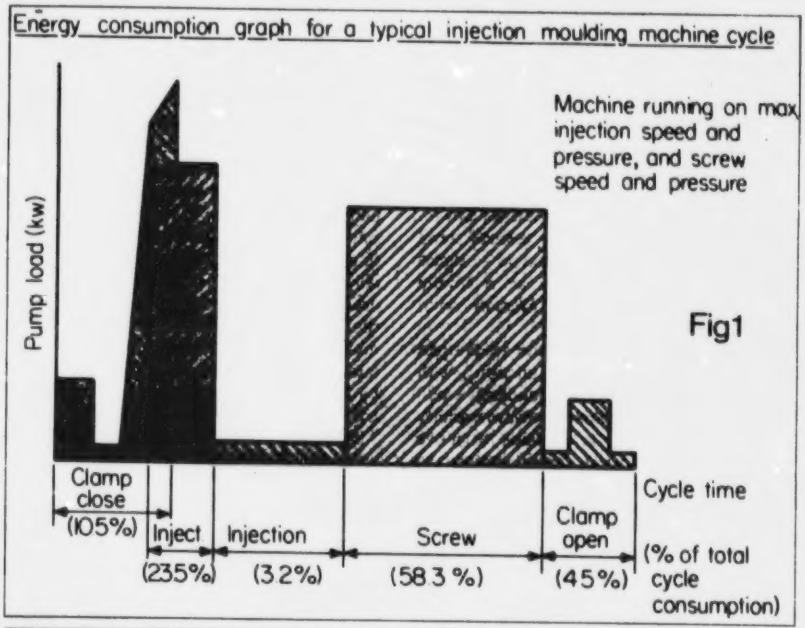


Fig1

1000 t mk 2 clamp system energy savings

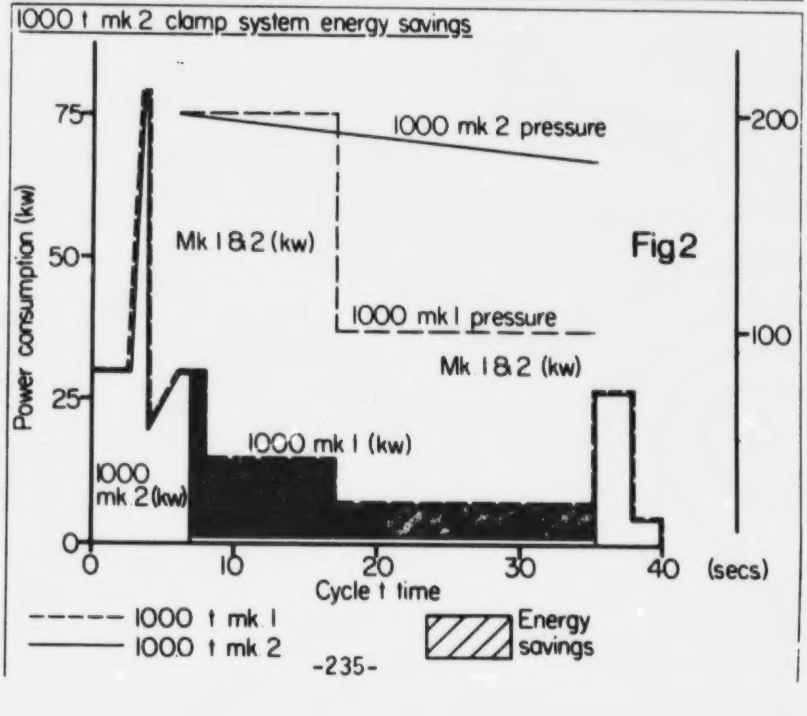


Fig2

***A V Chivers, BA, TEng (CEI), MIE, is chief engineer, Bone Cravens Ltd.**

Fig3

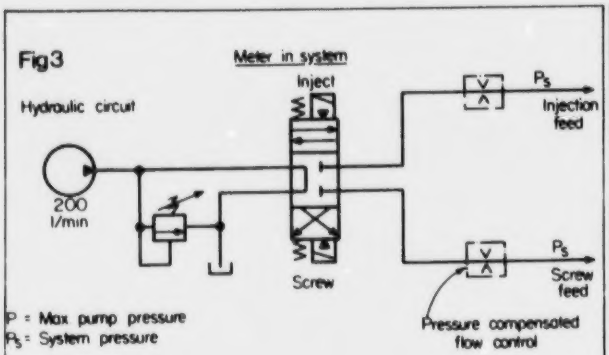
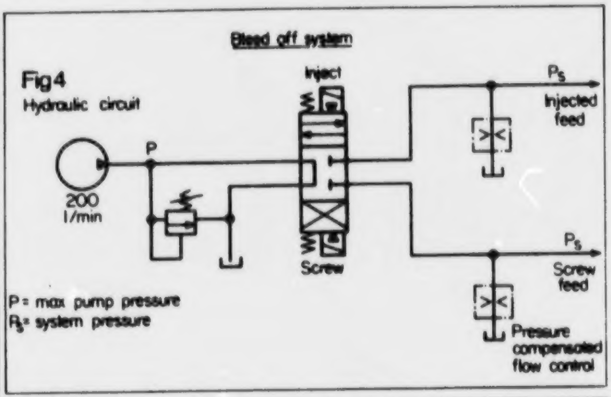

Meter in system
Hydraulic circuit
Inject
200
l/min
Screw
P_s
Injection feed
P_s
Screw feed
P = Max pump pressure
P_s = System pressure
Pressure compensated flow control

Fig4


Bleed off system
Hydraulic circuit
Inject
P
200
l/min
Screw
P_s
Injected feed
P_s
Screw feed
P = max pump pressure
P_s = system pressure
Pressure compensated flow control

Barrel heating system

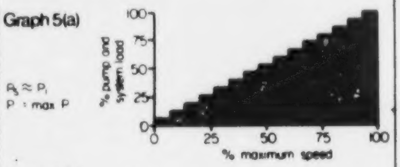
Electrical resistance heaters fitted to the barrel provide conductive heat which combines with the shear heat generated by the screw to give the required melt quality. Insulated heater bands and barrel guards are available which can reduce, under ideal circumstances, heater band energy consumption by up to 50%.

Experimental trials have shown, however, that when insulated heater bands and barrel guards are incorporated into a machine design, accurate control of the barrel temperature becomes almost impossible to achieve, due to over-shooting of the set temperatures as a result of the shear heat generated by the screw.

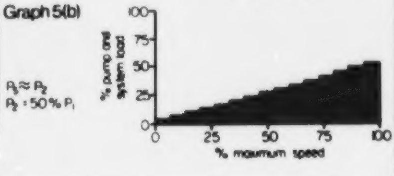
The amount of shear heat generated by a screw is a complex function dependent among other variables, on the polymer being processed, the screw geometry and the screw speed. It has become apparent on machines fitted with a 'universal' screw, that the barrel heat loss is one of the factors contributing to stable barrel temperatures, over a large range of processing conditions. Therefore, it would appear that insulated heater bands and barrel guards are most suitable for incorporation into machinery designed to run specific polymers under constant moulding conditions with a suitably designed screw.

As the majority of injection moulding machines are used to produce various products in a variety of polymers, it is apparent that the most practical method of minimising the energy consumption of barrel heater bands would be to incorporate into the machine design an insulated barrel guard (with non-insulated heater bands), which has a variable ventilation facility, thereby giving accurate control over the barrel heat losses.

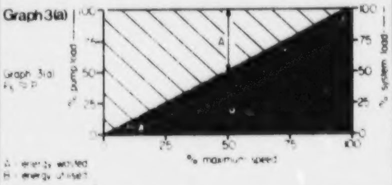
Graph 5(a)



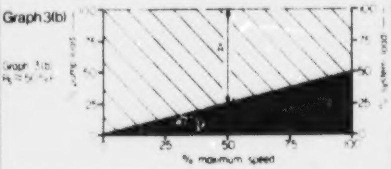
Graph 5(b)



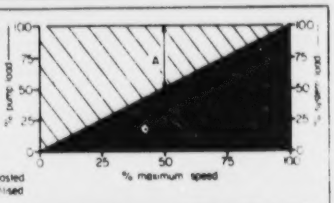
Graph 3(a)



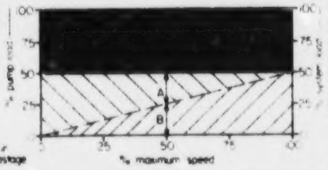
Graph 3(b)



Graph 4(a)



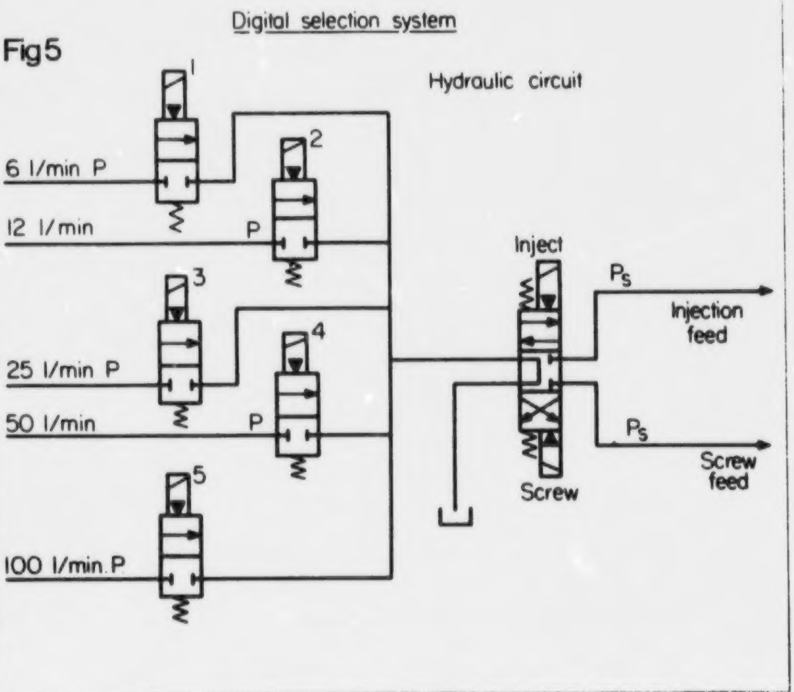
Graph 4(b)



It is probably worth noting that the advent of the vented barrel, which has increased the energy consumption of the heater bands (due to the increased L:D ratio of the screw and barrel), has eliminated the energy consumption of the drying equipment formerly required to pre-dry hydroscopic polymers. Whilst this has not reduced the energy consumption of the machine, it has reduced the overall energy consumption of the moulding plant.

Ref 1. Cincinnatti Milacron technical report volume II issue 3

Fig5


Digital selection system
Hydraulic circuit
1
2
3
4
5
6 l/min P
12 l/min
P
25 l/min P
50 l/min
P
100 l/min.P
Inject
Screw
P_s
Injection feed
P_s
Screw feed

straightforward comparison between installed motor horse power should not be taken as indicative of their power consumption capabilities.

Over the years, machine designers have incorporated certain features into their designs which has enabled the machine to function normally, but consume less energy, and it is work in this area which forms the major part of this paper.

Electric motor hydraulic pump

An injection moulding machine is not a particularly complicated piece of machinery. It consists basically of a clamp system which allows the mould to open and close and a reciprocating screw injection unit which plasticises the polymer in a heated barrel and then injects it, under pressure, into the closed mould. Most machine functions (except the barrel heating) are normally carried out and controlled by hydraulic oil flow and for this reason the machinery is fitted with electrical motors driving hydraulic pumps, which provide the required hydraulic oil flows for the stated three main functions.

- Clamp system
- Injection system
- Screw drive system

Clamp system

For many years, discussion as to the relative energy consumption of the direct hydraulic lock versus the toggle clamp have taken place. Comparison of the energy demand graphs of comparable direct hydraulic and toggle machines has shown that the energy consumed to open and close the mould is similar for either type of machine (Ref 1), however, the toggle machine does have an advantage over the direct hydraulic lock machine when the clamp has achieved full clamp tonnage. When a toggle machine has locked up, the pressure applied can be removed and the clamp will remain locked at full tonnage under the effect of the strain induced into the tie bars during lock up. On an hydraulic machine, the clamp pressure must be maintained by a low volume pump and this in effect wastes energy (although this may represent less than 10% of the total energy consumption of the machine).

A series of experiments carried out over the last four years has established that if the hydraulic pressure is locked into the hydraulic cylinder of a direct hydraulic lock machine, the clamp tonnage would then decay at such a slow rate (due to leakage) as to be insignificant during a normal moulding cycle. For example, the Bone Cravens Mark 2 range of machines incorporates, as standard, a pressure lock-in system which reduces clamp energy consumption to a minimum, giving substantial energy savings as illustrated in figure 2.

Injection screw drive system

The injection and screw plasticising functions of an injection moulding machine cycle use the majority of the cycle's energy consumption (see figure 1). Because of this, they have been considered by machine designers to be a prime target for achieving significant reductions in the total energy consumption.

Both screw and injection consume high volumes of oil at high pressures (and, therefore, high energy usage) and it is practical to consider both functions together. The most effective method of reducing energy consumption is to use only that energy necessary, thereby reducing wastage to a minimum.

The screw and injection circuitry on injection moulding machines has been steadily refined over the years to the point where, on the latest designs of machines, only the exact volume of oil required is pressurised to the required level, thereby consuming as closely as possible the amount of energy being usefully employed during that part of the cycle.

The evolution of the present day circuitry started with the Meter-in system, utilising one high volume pump, developed to the Bleed-off system, again utilising one high volume pump, and has now been superseded by the Digital selection pump system, which utilises various pump volumes combined to give the required flow rates.

Meter-in system

This original system (Fig 3) used to control high speed injection and screw speed, utilized a single, high volume, pump directed through two independent pressure compensated flow control valves adjusted to give the desired speeds.

This system required that the pump ran at full system pressure regardless of the pressure or speed requirements. Excess pressure and oil volume was dissipated across the pump relief valve and appeared as heat, subsequently removed by an oil cooler. Graph 3(a) shows the energy loss which can occur at various proportions of maximum speed on a system working at the maximum pump pressure.

It can be clearly seen that the lower a speed is selected, a greater proportion of the energy used by the pump is wasted. However, graph 3(b) shows a more serious weakness in the system.

Most machine systems, particularly during the screw function, require only a fraction of the maximum system pressure and as can be seen in the graph, the proportion of energy wastage increases dramatically with lowering of the system pressure and speed required.

Bleed-off system

This system was introduced to overcome the most serious weakness of the Meter-in system, as detailed below. The hydraulic circuit is shown in figure 4 and it can be seen that the only modification is that the pressure compensated flow control valves are no longer in the main pressure lines, but bleed-off excess oil direct to tank. This modification enabled the hydraulic pump to run at the system pressure and not continually on full pump pressure.

The modification had no effect when the required system was equal to the maximum system pressure [compare graph 3(a) and graph 4(a)] but it made significant energy savings on systems in which the system pressure was considerably lower than the full pump pressure. Graph 4(b) shows the energy saving over the Meter-in system as shown on graph 3(b).

Note that the Meter-in system gave accurate speed control, the flow control valve automatically compensating for pump flow variations. In the Bleed-off system slight pump flow variations affect the stability of the speed, but this was considered insignificant in comparison with the energy savings.

Digital selection system

This system is the latest development in the endeavour to reduce energy wastage to a minimum. The system dispenses with the pressure compensated flow control valves and consists of a multiple pump system controlled to give the desired speeds using the appropriate combination of pumps (see figure 5). The machine user can now select the appropriate injection or screw speed by merely selecting the appropriate setting on a control panel switch.

The system does not give infinitely variable speed control as did the Meter-in and Bleed-off systems, but discrete incremental steps between zero and maximum speed. For most applications this can be considered satisfactory. (A very small presure compensated flow control valve could be connected into the screw and injection pressure lines to bleed off a small volume of oil, should infinitely variable control be required).

As shown in graphs 5(a) and 5(b), the energy requirement is almost identical to the pump load, there being very little energy wastage. This system is extremely suitable for incorporation into servo-valve systems.

Servo-valve systems can exhibit the same energy wasting characteristics as Meter-in systems. If the directional control valve in figure 5 is replaced by a servo-valve, modern electronic control systems can be designed to automatically select the correct pump combinations to ensure an adequate supply of oil to the servo-valve. A pressure match system eliminates the problem of the pump running at maximum pump pressure and not the required system pressure.

Taking the heat off injection molding

You can't have it both ways: only those machines designed most closely for the jobs they are intended to perform can be most efficient. In injection molding, you can get big paybacks by optimizing several key areas: the design and selection of electric motors, clamping systems, heater bands, and pumps. If you can check out screw/barrel efficiency as well.

Bernie A. Olmsted
Reed-Prentice Div.
Package Machinery Co.
East Longmeadow, Mass.

We must face the fact, however unpleasant, that injection molding is an energy-intensive process. Because of its complexity, high degree of automation, and great productive capacity, it must rely upon component systems that are highly energy-dependent: electric motors on the clamp end that drive hydraulic pumps that develop the muscle to open and close clamps and resist cavity pressure during injection; electric motors on the injection end by which to develop the hydraulic force needed to move the melt into the mold and lay in the packing pressure needed to fill it out. And we can't overlook the fact that, generally, as you upscale the machine or increase its operating speed, you're going to need more power. That naturally spells more energy.

You're not through yet. Of the heat needed to melt the resin, some of it—sometimes all of it—will be shear heat, that is, heat developed from friction arising as the resin is forced through the narrow interface between the inside barrel wall and the edge of the screw flights. That's energy from the hydraulic system, but it's energy consumed nonetheless.

Heat that is directly applied, from heater bands ringing the barrel and spaced along its length, is yet another source of considerable energy consumption. Externally mounted, the bands must be able to maintain a heat gradient across the barrel wall while barrel heat is being dissipated from its outside surface.

The process, simultaneously, is being reversed in the mold. The heat injected into the resin to prepare it for injection must now be removed, usually by a circulating-water system. If the circulating water is taken directly from a municipal system, then the cost of the water must be counted an energy-dependent cost. Because water is becoming a scarce and expensive commodity, closed-loop systems have been installed. Sometimes they involve simple cooling towers, sometimes refrigeration, but always electric power to drive associated compressors and, at the very least, circulating pumps. If molds are run warm, then we may need as well a mold-temperature control, which uses electric energy to heat the coolant and operate the circulating pumps.

Materials-handling systems, conveyors, and scrap grinders, among major auxiliary equipment, themselves energy-intensive, but necessary minions of the highly automated masters they serve, must be regarded as integral parts of the process and each, thereby, accept a share of the load.

So, if we must be resigned to the energy-intensiveness of injection-molding systems, can we hope to make them more efficient? Can we maintain our throughput while reducing our kilowatt-hours or our Btus? Yes. But to do so, we must uncover hidden energy wasters in component machinery or in the process itself.

Suppliers of auxiliary equipment, as keenly aware of the problem as any machinery builder, are doing their utmost to bring energy-stingy equipment to the market. We at Reed are fully confident of their ultimate success.

At Reed, however, building energy-efficient machinery has been a long-standing goal, sought after long before the oil crunch of 1974 opened the eyes of the industrialized world to the precious nature of energy; long before the first shocks of the crisis, felt almost immediately by our industry as a scarcity of feedstocks, threatened to materialize; long before the perception that shortages would be chronic and that the world could, unless measures were taken to forestall it, run out of energy entirely.

Back in the 1950s, Reed, in conjunction with General Electric, developed a method of calculating the root mean square horsepower used by a molding machine under average cycle conditions. Since 1966, we have isolated four areas in the molding machine where significant savings in energy can be exacted. In time, others will be added to the list. We believe, however, that through our approach, a design philosophy based on careful analysis of details and an emphasis on fundamentals, we have been able to point the way.

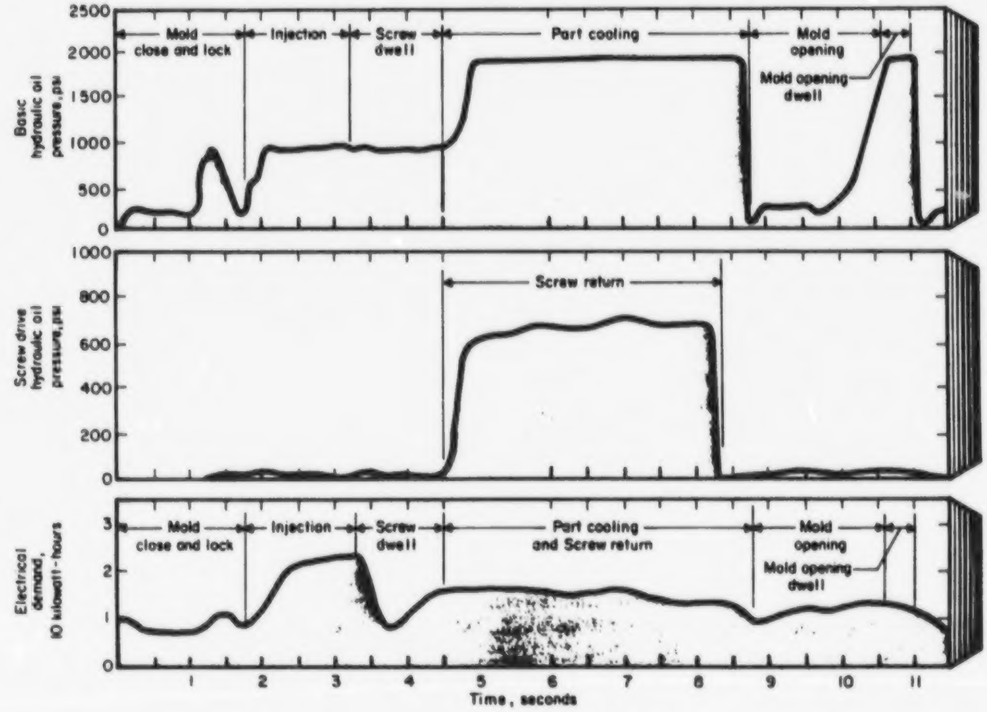
Selecting motors (see the *Figure* and *Table 1*). We calculated the power requirements of the electric motors driving the hydraulic pumps that run both the screw and the basic machine components over a single cycle; we then tested our calculations against an actual run. Since straight-line assumptions were made for the theoretical calculations, they tend to be more conservative. In either case, the results can be used to select smaller motors that can operate at 200 percent torque overloads for 25 percent of the cycle. Looking at the theoretical calculations (*Table 1*), for example, a motor rated at about 22.2 horsepower will be acceptable, although power requirements for portions of the cycle can reach 36.4 horsepower. Similarly, for measured data, nameplate motor requirements would be about 14.17 horsepower, although peak requirements run to 21.6 horsepower. Only when you realize that an electric motor operating without load draws between 40 and 50 percent of its rated power can you appreciate the saving in energy by downsizing.

Clamping and screw/barrel design. To check out the energy efficiency of our newest machines (TG series), which was high on our list of design objectives, we ran a series of tests on our older machines and on competitive machines as well.

We need to separate machine-drive energy from heater energy in our tests because we want to compare the relative efficiencies of screw/barrel designs. But we also want to isolate the energy levels in terms of the heat profile. It is possible to vary the amount of applied heat in accordance with the amount of screw-drive energy that is converted to heat by shear.

In our first test, we compared a 250-ton, 20-ounce, 40-horsepower TG machine with one of our older 200-ton, 20-ounce, 30-horsepower TD machines, using the same mold. The results were gratifying. Production by the TG machine was higher by 23 percent while energy consumption was 22 percent less.

In a subsequent test, designed to evaluate the energy used to close and lock the clamp, then unlock and open it, we compared the efficiency of



Profiles of measured basic and screw-drive hydraulic pressures and of the corresponding electrical demand over an 11-second machine cycle running high-impact polystyrene.

Table 1. Power requirements for an injection-molding machine running high-impact polystyrene calculated by the root mean square method from theoretical (T) and measured (M) data.

Machine action	Pump pressures, psi: Screw drive pump T	Screw drive pump M	Both large and small basic pumps T	Both large and small basic pumps M	Small basic pump only T	Small basic pump only M	Power delivered, horsepower T	Power delivered, horsepower M	Cycle time, seconds T	Cycle time, seconds M	Power^2 × time, horsepower-seconds T	Power^2 × time, horsepower-seconds M
Mold close	[redacted]	0	[redacted]	200	[redacted]		[redacted]	11.4	[redacted]	1.19	[redacted]	155
Mold lock	[redacted]	0	[redacted]	1000	[redacted]		[redacted]	11.4	[redacted]	0.63	[redacted]	82
Injection	[redacted]	0	[redacted]	1000	[redacted]		[redacted]	21.6	[redacted]	1.6	[redacted]	745
Screw dwell	[redacted]	0	[redacted]		[redacted]	900	[redacted]	7.5	[redacted]	1.45	[redacted]	81.7
Part cooling and screw return	[redacted]	700	[redacted]		[redacted]	1900	[redacted]	16	[redacted]	3.5	[redacted]	895
Mold open	[redacted]	0	[redacted]	300	[redacted]		[redacted]	8.5	[redacted]	1.9	[redacted]	137
Mold open dwell	[redacted]	0	[redacted]		[redacted]	1900	[redacted]	12.2	[redacted]	0.64	[redacted]	95.3
Totals	[redacted]		[redacted]		[redacted]		[redacted]		[redacted]	10.91	[redacted]	2190.0

From theoretical data: Root mean square horsepower = $(4930.9/9.49)^{1/2} = 22.2$
From measured data: Root mean square horsepower = $(2190.0/10.91)^{1/2} = 14.17$

the 250TG with a Reed 300TE, also a 40-horsepower machine. Whereas the 300TE used 38.7 horsepower to perform these operations, the 250TG could do the same thing on an average horsepower of only 10.7. So the patented clamp system of the TG series proved energy-efficient.

Band heaters. In comparative tests made with competitive equipment using mica band heaters (see *Table 2*), we were able to evaluate and compare the efficiency of mica band heaters with the ceramic heaters on our equipment. The ceramic heaters were found to use 23 percent less energy, but we did note a problem. Whereas power consumption over 10-minute intervals was predictable for the mica bands, it was not for the ceramic bands. We suspect that the difference lies in the half-inch insulation surrounding the ceramic bands. We attribute the erratic behavior to a wave effect produced by barrel heat trapped there by the insulation. Further testing is indicated.

Costing out the comparison including the heat consumed by the motor drive system (*Table 2*), you would save $3024 with the Reed machine if the two machines were run 24 hours a day, seven days a week, for

Table 2. Comparative energy consumptions of two 200-ton injection-molding machines molding high-impact polystyrene.

Condition	Reed 200TG	Competitive machine
Machine and molding specifications		
Number of mold cavities	16	16
Shot size, ounces	2.3	2.3
Cycle time, seconds	6.6	6.6
Screw size, ounces	10.5	12
Power rating, horsepower	30	40
L/D ratio	20 to 1	20 to 1
Heater bands, type	Ceramic (1/2 inch, insulated)	Mica (half cover)
Energy measurements over one hour of operation, kilowatt-hours		
Motor drive system	16.6	23.5
Heaters	1.3	1.6
Total	17.9	25.1
Total energy cost operations for 8400 hours at 5 cents per kilowatt-hour, dollars	7518	10,542

Saving, dollars: 10,542 − 7518 = 3024
Saving, percent: 40

50 weeks, and your energy costs were 5 cents per kilowatt-hour.

Obviously, these are the results of only one test, and the data will change with changes in the mold, material, and cycle time. We have, however, run other tests against competitive machines. Our greatest saving thus far has been the 25-percent saving in heater consumption.

Pumps. The selection you make in pumps for injection can be the basis for further energy saving. Most hydraulic systems use fixed-displacement pumps in varying combinations. Usually more pump capacity is available than the clamp end needs, a condition engendered by the high demand of the injection end to move melt into the mold with rapidity. Flow-control valves are used to regulate injection speed by restricting the flow of this large volume of oil—but at a waste of energy. You cannot hope to save energy if, for example, in a system able to deliver a total of 40 gallons per minute from two fixed-displacement pumps, neither one is sized to the 20-gallon-per-minute flow required for a particular material. Throttling down the flow of oil until desired injection speed is obtained creates a pressure drop in the system and the consequent need for the drive motor to compensate for it by delivering more power. Further, the heat picked up by the excess oil at a relief valve and at the throttle valve, in returning to the tank, must be removed by a heat exchanger. Not only is more energy needed to operate the drive motor, but more water must be used to cool this wasted energy that ends up as heat in the oil.

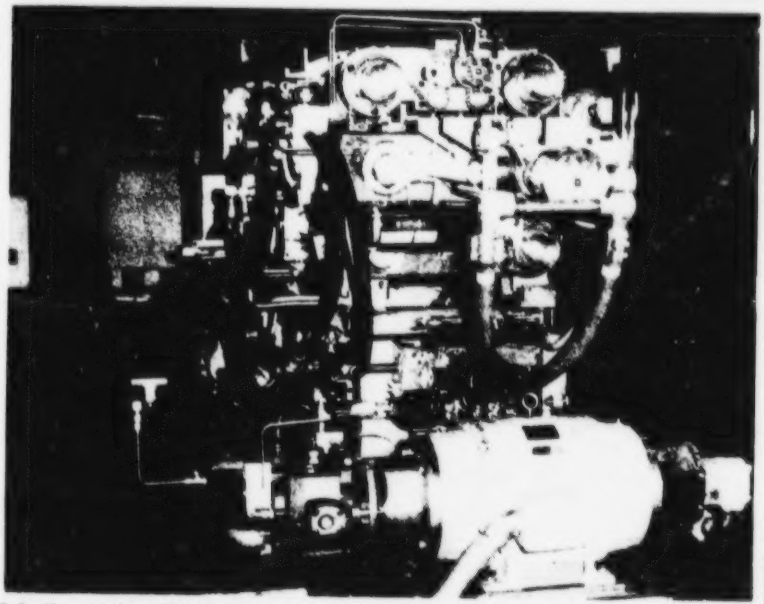
How to save energy on your present equipment

- Hold clamp pressures to the minimum needed to fill the mold.
- Increase gate sizes to permit lower injection pressures and stock temperatures.
- Use the correct heat profile for the screw and material; profiles for different sizes or makes of machines won't work.
- Remember: higher hydraulic pressures cost more to achieve.

We think an effective way to save energy here is to select and match pumps precisely to demand. ☐

'Variable pumps' mean anything to you? It should. Here's why

New controls and new design features are moving them out of the small-machine league into bigger equipment, where energy efficiency counts for more. And big energy savings mean faster payback



Injection machine fitted with variable pump. [Photo, Reed-Prentice]

Already proved as energy misers on small machines, ultra-efficient variable-displacement pumps are now tackling bigger jobs in injection molding and reaction injection molding (RIM).

Advances in pump hydraulics and controls enable reliable and responsive variable pumps to be economically "stacked" (on a more-affordable single control system), thus extending their use far beyond previous machine-size limits of around 100 tons. Hundreds of machines in the 200- to 700-ton range have been retrofitted with multiple variable pumps, and OEM injection presses more than twice the size of earlier variable pump machines are being introduced.

Variable pumps have been criticized by some as troublesome devices that engender prohibitive complexity and maintenance. But that perception is changing.

One molder, Tupperware, Inc. is reported to have saved nearly 30% from previous energy utilization on more than 400 fixed-pump machines in the 200 to 700-ton range converted since the beginning of last year. Other molders report amortization of $10,000 variable-pump conversions in less than seven months, and standardized installation procedures have slashed initial retrofit costs. According to Parker Hannifin Corp.[a], a leading pump retrofit supplier, some companies have cut machine conversion downtime to one shift with jigs that quickly align the new pump on each machine size and type.

With fast-switching microprocessors, the ability to quickly combine multiple fixed pumps in response to molding cycle changes has narrowed (but not entirely closed) the energy gap between pump output and less-than-peak machine flow demand. Molders who have converted state-of-the-art multiple fixed pump presses report significant energy savings. Sherwood Medical Products, Deland, FL, says it has achieved more than 20% energy savings on some machines less than two years old. For example, a modern 275-ton press at the company's Ballomoney, Ireland, plant was converted from three microprocessor-selectable Sauer fixed-vane pumps (84 gal./min. total capacity) to a system comprising two variable-displacement vane pumps at equal output, with reported energy reduction of 22%.

Parker Hannifin engineering manager Charles H. Whitmore says variable pumps "eliminate the holes in fixed-pump response," and that a good measure of this is reduction of heat loss through the hydraulic fluid tank heat exchanger when multiple fixed-pump machines are converted to a variable pump system. Heat (and energy loss) is generated, says Whitmore, when available pump combinations do not match machine demand. For example, excessive flows are generated at points in the machine cycle at which three fixed pumps (and five combinations of flows and pressures) cannot come up with an appropriate power level.

Retrofitters of variable pumps are saving additional energy by retailoring hydraulic system capacities to the job. Sherwood Medical's retrofit program, under which more than 200 presses (ranging from 150 to 660 tons) have already been converted, is based on split-level machine utilization: machines that are converted observing original specs, and presses whose pump capacity has been derated for dedicated use. OEM pump capacity is retained on multi-purpose machines for potential fast-cycling jobs; on machines tied to long-running molds, total energy savings realized can reportedly be up to 20% greater.

Where they don't fit

Examples are not always as favorable, admit variable-pump suppliers. On machines that are consistently operated near the peak of their performance range (as in fast-cycling presses for rigid packaging and disposable containers) little is gained by variable-pump conversion. Fixed-pump machines use relief valves to limit pressure; flow control and needle valves to limit speed; and unloading valves to dump excess flows from pumps to tank. In flat-out operation, cycle periods of low pressure or flow demand requiring such valving restrictions

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a : For complete addresses of supplier companies mentioned, see list at end of article.

are so abbreviated that not enough energy is saved to justify conversion.

However, variable-pump suppliers claim that the majority of machines used in other molding operations are rarely operated all-out. Parker Hannifin reports that of the more than 1200 machines it has supplied with variable pump conversions, fewer than 55 were utilized at full-rated capacity.

For example, the company says a typical molding assignment on a 300-ton multiple fixed-pump injection press running parts on a 12-sec. cycle requires less than 70% of machine plasticating capacity. The setup screw speed of 55 r.p.m. calls for a hydraulic flow of 22.4 gal./min. on this machine; resin viscosity backpressure on the hydraulic screw drive requires 1000 p.s.i. generated at the pump.

These molding conditions need less power than the 33 gal./min, 1750 p.s.i. fixed pump delivers at maximum efficiency, and energy is wasted across the needle valve and relief valve used to throttle down fixed-pump flow and pressure to the requirements of the job. With a variable pump conversion, throttling is no longer required; the pump automatically adjusts to machine pressure and flow demands.

Growing OEM activity

Eliminating throttling valves that waste energy (but are needed to tailor flows of fixed pumps) has been practiced for years on variable-pump-based small machines from such companies as Battenfeld, Boy, Engel Canada, and Polymer Machinery (Arburg).

Bigger machines now being introduced use as many as five variable pumps compared to the single-pump systems of these smaller machines: Cincinnati Milacron's new 375-ton multiple variable-pump machine, called Hydradamp 375-32, is available with two pump configurations. A medium-performance version combines fixed and variable pumps to achieve fast cycles at lower hydraulic system cost; a "dedicated" version based on multiple variable pumps is targeted for molding assignments with lower plasticating rates and longer cycle times.

Multiple variable-pump systems are also emerging on other types of processing equipment, including reaction injection molding machines, structural foam presses, and blow molding machinery. Milacron has switched from the multiple fixed-pump system used on its RIMM 90 and RIMM 125 metering units and presses to a selectable variable-pump combination comprising four Parker Hannifin PVV 142 variable pumps (to deliver total hydraulic flows of 168 gal./min. at 1200 r.p.m.).

U.S. technology lead

Significance of these new, higher-capacity multiple variable-pump systems is that for many years it was thought to be next to impossible to accurately control and coordinate the outputs of more than one variable pump on a single machine. But in the U.S., where multiple variable-pump technology is taking the lead over Europe, control concepts have been developed that enable outputs of up to five variable pumps to be accurately "modulated" to respond to a full range of machine functions.

One such control concept recently patented by Parker Hannifin involves volume feedback signals from each pump. These signals are compared with a reference signal to match flow demands of the machine system by cutting pumps in and out of a multiple pump system as well as varying output of each pump. Additionally, a "not-to-exceed" pressure signal is fed back from line transducers to match flow delivery to pressure requirements, avoiding the excessive pressures (and energy losses) of volume feedback-only pump control.

In this way, the mode of pump control is automatically switched from pressure to flow and back again, depending on whether pressure or flow is the key variable in a machine function, as in screw plastication (pressure) or injection (flow volume). A variable-pump system controlled in this manner is designed to operate as accurately as a servovalve for process controls.

As for machine cost increases, it's not yet entirely clear how much extra processors may have to pay for variable pump technology. However, it's certain that such machines won't be priced out of reasonably fast payback rates—estimated from one to two years based on the 30 to 40% energy savings they can deliver. [J.S.]

For more information . . .

Battenfeld, East Providence Div., 231 Ferris Ave., E. Providence, RI 02916. (CIRCLE 225 FOR READER SERVICE)
Boy Machines Inc., 365 Oser Ave., Hauppauge, NY 11787. (CIRCLE 226 FOR READER SERVICE)
Cincinnati Milacron, Plastics Machinery Div., 4165 Halfacre Rd., Batavia, OH 45103.
Engel Canada Ltd., 545 Elmira Rd., Guelph, Ont., Canada N1H 6R1 (CIRCLE 227 FOR READER SERVICE)
Parker Hannifin Corp., 17325 Euclid Ave., Cleveland, OH 44112. (CIRCLE 229 FOR READER SERVICE)
Polymer Machinery Corp., 154 Woodlawn Rd., Berlin, CT 06037. (CIRCLE 230 FOR READER SERVICE)
Sperry Vickers, 1401 Crooks Rd., Troy, MI 48084. (CIRCLE 231 FOR READER SERVICE)

Note: Companies listed here are only those mentioned in the foregoing article. For complete injection-equipment supplier lists, consult the directory section of Modern Plastics Encyclopedia 1981-82, p. 868.

Sperry bets on variable-pump growth in bigger injection machines

Major hydraulics component supplier Sperry Vickers has announced that it will also be marketing a range of variable vane pumps that can be used in multiples to power large tonnage machines.

Sperry says that more than 25% of *all* primary plastics machinery could be based on variable pumps 10 years from now, for reasons of increasing reliability of pump designs and energy cost increases that mandate state-of-the-art machine efficiency. The company will begin its introduction of variable vane pumps (in sizes from 21 to 60 gal./min.) in mid-1983 to meet this expected demand, with prototypes for OEM testing made available earlier.

Design innovations in Sperry's new pump line, including interchangeable cartridges and hydraulic balancing, are aimed at lower maintenance and increased versatility in use. Cartridges can be interchanged to compensate for wear without removing the pump from its mountings, and dual, opposed inlet and outlet ports in each cartridge are said to balance the rotor so that minimum load is placed on rotor bearings for longer life.

Adaptations to multiple-pump use include through-drive options and a full range of controls, including pressure compensating, load sensing, torque limiting, and displacement, in either hydro-mechanical or electro-hydraulic configuration.

Higher pressure ratings of 3000 p.s.i. are said to permit use on injection machines that require variable hydraulic pump systems over 2000 p.s.i.

Projected pump sound levels from 67 to 72 db(A) at 1200 r.p.m. are well below OSHA requirements, and filtration levels of 25 microns can be handled by existing machine filtration systems, says Sperry. The new pumps are claimed to be over 95% volumetrically efficient, and to provide fast response times for effective servo process control—with on/off stroke times under 80 milliseconds.

High energy yield with NETSTAL injection moulders

1. INTRODUCTION

A comparison of figs. 1 and 2 clearly shows that the higher the output in injection moulding (mass produced articles), the lower the proportionate machine costs. The fixed investment costs, in particular, are reduced, whilst energy costs rise. They represent the biggest proportionate variable part of the machine costs, which is becoming more and more important from one year to the next. If productivity is to be increased through increased yields and outputs, the expected energy requirements should be calculated in addition to the capital investment when buying a high performance injection moulding machine.

This article explains the effect of clamping unit construction, the machine drive and production rate of the machine on energy consumption, and shows in what way NETSTAL injection moulding machines offer advantages.

2. DEFINITION OF ENERGY CONSUMPTION

Let us first define what exactly is meant when we speak of energy saving in connection with injection moulding. Seen theoretically, this definition is easily arrived at, taking the form of a constant which divides the dissipated energy by the energy put in. Problems may arise where it is necessary to describe more accurately the "energy put in" and the "energy dissipated".

A practical and simple method of quantifying energy consumption in injection moulding machines consists of determining the factors which interest the moulder, e.g. the amount of electrical energy (kilowatt hours) needed to make a unit weight (kg) of end product.
It is best, therefore, to use a constant, derived from kWh per kg, to characterise the energy consumed during a specific process. The smaller this constant, the greater will be the energy savings effected.

3. ENERGY REQUIREMENTS AND DESIGN PRINCIPLES FOR THE CLAMPING UNIT

The effect of clamping unit design on the machine's energy requirements was investigated by Husky (*), with the aid of two series of tests with the same mould used on two similar machines with differently designed clamping units. The mould used was a six-impression tool for packaging containers, the material being polystyrene. The first clamping unit was of the mechanical, toggle type, the other a fully hydraulic one. As we have said, both machines were very similar, for example the same injection unit and same heating capacity were used. Locking force, temperature settings, screw speed and injection pressures were the same in both tests.

First of all, both machines were run at the same cycle time, this being governed by the minimum possible time when using the fully hydraulic machine. Fig. 3 shows that the toggle machine used about 30% less energy per kg of moulded material compared with hydraulically driven machines.

Evidently, therefore, the design of the clamping unit influences the energy consumption and energy saving that can be achieved with an injection moulding machine. It was found that the fully hydraulic machine is less energy-efficient than the mechanically driven toggle machine, a fact that is understandable when one considers that, purely from the design point of view, it has more sources of energy loss.

We need only think of the poor efficiency of the hydraulic pump, the losses that occur in hydraulic lines, valves etc. Mechanical as well as hyhydraulic toggle mechanism show fewer such losses than a fully hydraulic machine. In the case of an hydraulically driven toggle mechanism around 20 times less oil need be circulated per cycle in the clamping unit. There will thus be a greater trend towards toggle machines in the future.

4. ENERGY REQUIREMENTS AND DRIVE DESIGN

Three hydraulic drive systems can be used for injection moulding machines:

- constant delivery pump operation
- accumulator operation
- variable delivery pump operation.

To find out the relationship between the minimum energy required ("ideal, imaginary variable delivery pump") and the energy used in injection moulding when using constant delivery pumps or accumulators, NETSTAL carried out moulding trials.

The following is an example:

Moulding:	"Scraper"
Length about:	160 mm
Width about:	60 mm
Wall thickness:	4–10 mm
Max. flow path:	250 mm
Cavities:	2
Moulding compound:	Luran 368 R
Shot weight:	53.3 g
Machine:	Neomat 350/120
Cycle time:	38.1 s

The amount of oil used by the most important parts of the machine, i.e. the oil motor, injection cylinder, auxiliary clamping cylinder and clamping cylinder was measured over a period of time, together with the resultant decrease in pressure. The power requirements for each component at any given moment could therefore be determined.

The minimum necessary amount of energy used by each of the above machine components was determined from the measured parameters. Let us assume that this represents the energy used by an imaginary, infinitely fast variable delivery pump of ideal efficiency, in a machine offering no resistance. This minimum necessary energy consumption was then compared with the energy used in the case of constant delivery pumps and accumulators.

Fig. 4 contains the energy values calculated for constant delivery pump and accumulator operation, as well as the cost invloved, compared with the maximum necessary energy consumption.
It was found that operation with constant delivery pumps required much more energy than using accumulators.

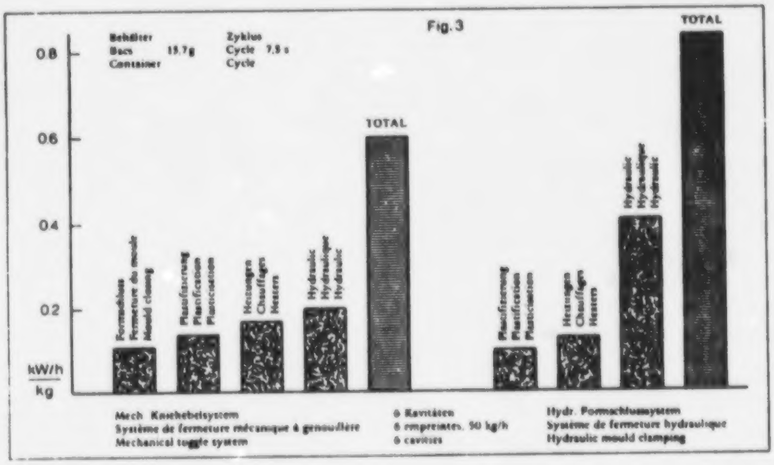
KOSTENART CATEGORIES DE COUTS TYPE OF COSTS	MASSENARTIKEL GRANDES SERIES MASS PROD. ARTICLES	TECHNISCHE TEILE PIECES TECHNIQUES TECHNICAL ARTICLES
Materialkosten **Frais matière** **Material costs**	**62 %**	**35 %**
Maschinenkosten **Frais machines** **Machine costs**	**15 %**	**20 %**
Werkzeugkosten **Frais outillages** **Mould costs**	**8 %**	**15 %**
Personalkosten **Frais main d'œuvre** **Wage costs**	**10 %**	**15 %**
Sonder- und Gemeinkosten **Frais extraordinaires indirects** **Extra and fixed costs**	**5 %**	**15 %**
Selbstkosten Prix de revient Total costs	100 %	100 %

KOSTENART CATEGORIES DE COUTS TYPE OF COSTS	MASSENARTIKEL GRANDES SERIES MASS PROD. ARTICLES	TECHNISCHE TEILE PIECES TECHNIQUES TECHNICAL ARTICLES
Stromkosten **Frais éléctricité** **Electricity costs**	**35 %**	**15 %**
Wasserkosten **Frais eau** **Water costs**	**20 %**	**4,5 %**
Hilfs- und Betriebskosten **Charges auxiliaires d'exploitation** **Subsidiary and operating costs**	**1 %**	**0,5 %**
Fixe Anlagekosten **Frais fixes matériels** **Fixed investment costs**	**44 %**	**80 %**
Maschinenkosten Frais machine Total machine costs	100 %	100 %

Hydraulic accumulators gave better resultats in the above mentioned test compared with constant delivery pumps wherever large amounts of oil, at high pressure, were needed. This is, in fact, a characteristic feature of modern injection moulding machines where injection speeds of 1000 mm/s and more are required. Such high injection speeds can, in fact, be achieved with pumps as well as accumulators, although in the former case higher installed drive power is required so that there is an increasing trend towards accumulator machines which use less energy.

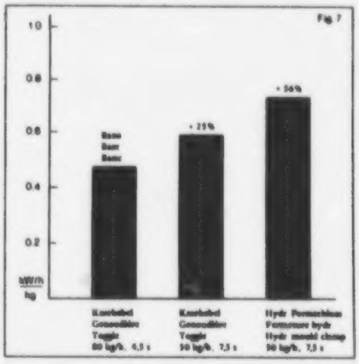
This is illustrated by fig. 5 which shows the injection capacity and ram speed as a function of the working pressure of the injection cylinder for a pump machine and an accumulator machine respectively. If one compares the maximum attainable injection capacity of the accumulator machine with the electric power of the motor which drives the accumulator charging pump (which was 22 kW), one finds that this is about twice as high in the present case (44 kW). It can, however, be three or even four times as high.

Compared with the use of a single constant delivery pump, the use of several such pumps, with different throughputs, is an improvement of energy efficiency. Here we should however point out the drawbacks compared with accumulator operation, namely increased load on the mains system, higher connected loads and more noise.



Energy consumption per kg processed polymer material, determined for the same mould, using a toggle machine and a fully hydraulic machine respectively, both about the same size and using identical settings.

Fig. 3 points in the same direction. In a second series of tests, the same mould was used on a toggle machine with faster cycles, so that shorter cycle times were achieved.
Fig. 7 shows the results obtained.



One final word on variable delivery pumps. Although the results obtained show that they offer advantages from the energy point of view – for a lot of energy is destroved by throttling, both in accumulator and in pump operation – their disadvantages relate to throughputs, noise and parallel operation of the machine parts.

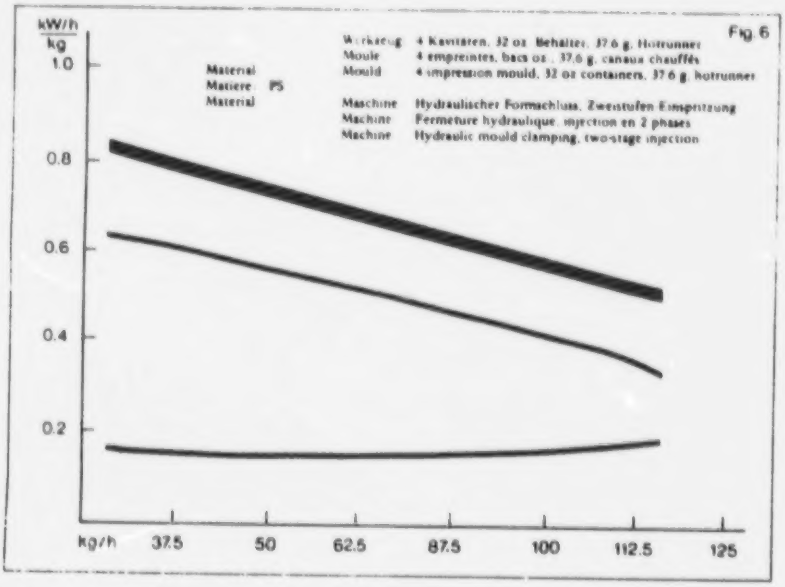
The throughputs of variable delivery pumps on the market today are limited. Nominal throughputs are only up to about 180 l/min, and response periods up to 500 ms, which is far below the present requirements for heavy duty machines, namely 1800 l/min and 50 ms respectively and must therefore be regarded as unacceptable. A variable delivery pump moreover can serve only one machine part, e.g. the mould opening mechanism. Simultaneous metering is not possible, nor, in most cases, is simultaneous core pulling or ejection. For these operations it is necessary to use additional systems. The simultaneous use of several variable delivery pumps is generally not feasible because of the high financial outlay involved, as well as the amount of noise the make. Whereas normal pumps have a noise level of 61 dB, variable delivery pumps can reach 68 or even 78 dB.

The fact that only one machine part can be operated at a time need not necessarily be due to the use of variable delivery pumps, but may have reasons relating to the hydraulic construction. Wherever this is the case, the machines have but limited use and usually involve longer cycle times.

Verbraucher Apparells hydrauliques Machine component or operation	Regelpumpe Pompe à débit hydr. Control pump	KONSTANTFORDERPUMPE POMPE A DEBIT CONSTANT CONSTANT DELIVERY PUMP		AKKUMULATOR ACCUMULATEUR ACCUMULATOR	
	(N = 1) (10⁴ Nm)	Energiebedarf Energie requise Energie requirem. (10⁴ Nm)	Mehraufwand Surcroît équival. Extra demand (%)	Energiebedarf Energie requise Energie requirem. (10⁴ Nm)	Mehraufwand Surcroît équival Extra demand (%)
Olmotor Moteur hydraulique Hydraulic motor	2.27	4.86	114	3.73	64
Spritzzylinder Vérin d'injection Injection zylinder	0.48	3.62	654	1.13	135
Formöffnung Ouverture du moule Mould opening	0.18	0.62	244	0.56	211
Hilfszylinder Vérin auxiliaire de fermeture Auxil. cylinder mould closing	0.14	0.47	235	0.28	100
Druckaufbau für Verriegelung Prod. pression de verrouillage Pressure build-up locking syst.	0.07	0.25	257	0.15	114

Fig. 4

Results of increased consumption of various hydraulic machine components, for constant delivery pump drive and accumulator drive respectively, compared with the minimum necessary energy consumption measured on the machine component



Energy requirements per kg processed polymer materials vs. production rate

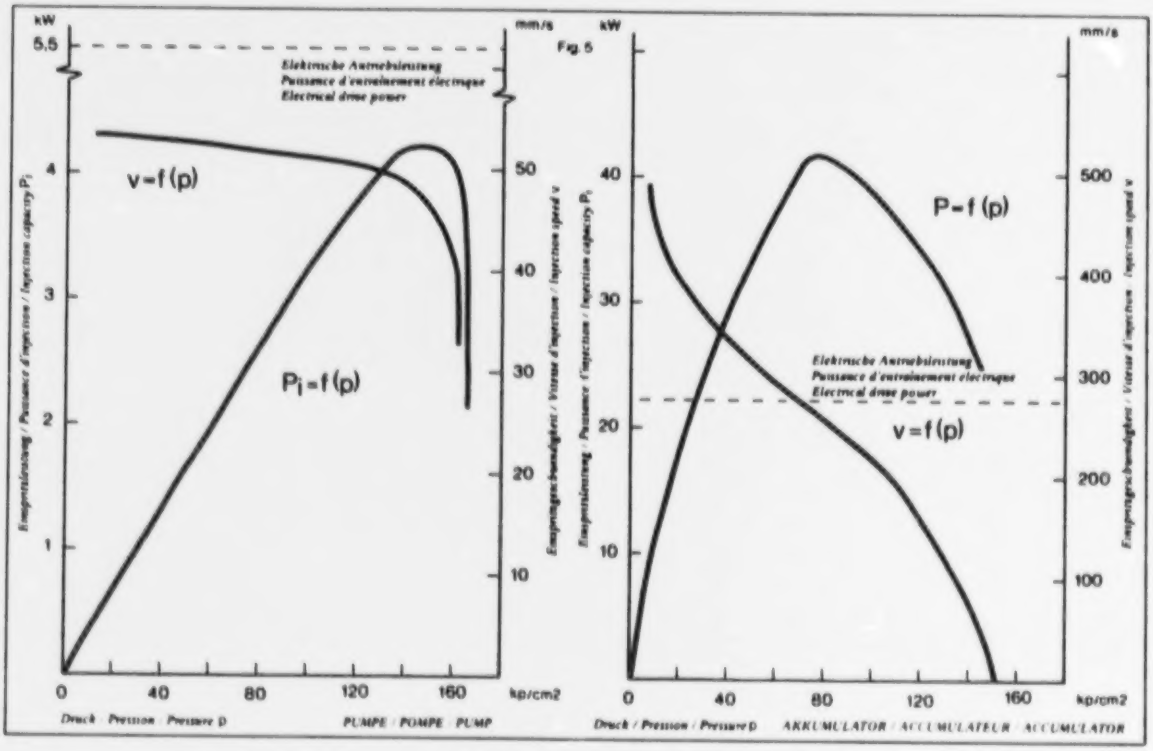


Fig. 5

Injection capacity and plunger speed vs. pressure of injection cylinder, for constant delivery pump drive and accumulator drive respectively, compared with the installed pump capacity

5. ENERGIE REQUIREMENTS AND MACHINE OUTPUTS

Here, too, plausible results have been obtained by Husky (*), who have determined the relationship between energy requirements and machine outputs.
In the first series of tests, an injection moulding machine with an hydraulically operated clamping unit, equipped with a four-impression mould for a packaging container was used, the material being polyethylene. The mould and machine were operated with four different cycle times, all other peripheral conditions remaining the same.

The results are shown in fig. 6. The text shows that the electrical energy requirements of mould and heaters per kg of moulding compound are independent of the production rate. On the other hand, the diagram shows that the energy consumption of the electric motor per kg moulding compound clearly decreases with increasing output.

The sum total of the two curves indicates low-energy operation at high production speeds, i.e. at increased outputs on the same machine.

These tests show that all attendant circumstances and peripheral conditions which contribute towards the slowing down of cycle times, e.g. insufficient cooling capacity, slow movements, the impossibility of carrying out several hydraulic functions simultaneously, e.g. opening, metering, ejection, affect the energy efficiency of the machine. The underlying reasons will come as no surprise to the experienced moulder or engineer. The results demonstrate that idle running and radiation losses are disadvantageous from the energy point of view, so that shorter cycle times should be the aim, since they enable better use to be made of the energy.

6. ENERGY REQUIREMENTS AND SAVING OF HEATING ENERGY IN INJECTION MOULDERS THROUGH INSULATING THE CYLINDER

To reduce heat loss of the plasticising cylinder to a minimum, this can be insulated with a new kind of insulating pad which is available also for NETSTAL machines (fig. 8).

These pads are wrapped round the cylinder's band heaters rather like a quilt, and fastened with quick-action clamps. Protruding parts such as band heater connections, thermocouples etc. are allowed for.

These insulating pads are about 20 mm thick and consist of non-ageing glasscloth filled with insulating mineral wool. They will withstand temperatures of up to about 500° C.

The energy savings vary, but in most cases are enough to make up for the financial outlay within a few months.

Advantages:

- savings of heating energy (measured values 10 – 38%)
- more even heating of moulding compound
- effects of draughts are eliminated
- no more risk of injury or burns
- reduced heating-up times when starting up the machine
- reduced switch-on frequency of band heaters
- easy to fit.

Disadvantages:

- **poorer dynamics for the controlling of the cooling phase**
- **risk of heat accumulating when the cycle is interrupted.**

7. COST EXAMPLE, SAVINGS POSSIBLE THROUGH MORE EFFICIENT UTILISATION OF ENERGY

The cost of electrical energy depends on the location of the moulding shop and will vary accordingly. Time is another influencing factor. Nevertheless, there are two general factors which contribute towards the price per kilowatt of electricity supplied:

1. Electricity charged at the peak rate (e.g. SFr. 93.– per kW)
2. Energy requirements
   per kWh, e.g. SFr. 0.093 peak rate,
   per kWh, e.g. SFr. 0.051 off-peak rate

Fig. 9 gives a cost calculation example for the annual electricity costs for an injection moulding shop with ten machines. The example has been based on the above mentioned average costs.

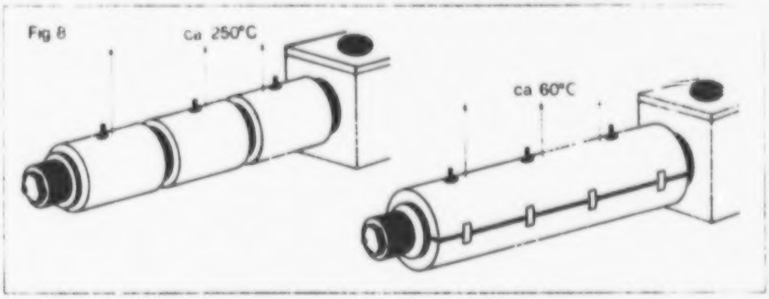
The purpose of any discussion involving the question of energy is to reduce its cost. Let us therefore assume a 20% saving of energy on the part of the machine. Here we must also consider that the machine is not responsible for the entire energy consumption. We can therefore assume that this energy consumption accounts for about half the total energy used in the entire moulding shop. In this case, the energy saved in the above example would be the not inconsiderable amount of SFr. 32,250.– p.a.

SUMMARY

The tests described above demonstrate that machine design has a definite effect upon the energy consumption of an injection moulding machine. Certain NETSTAL machine designs offer unequivocal energy advantages for specific applications. These can be summarised as follows:

- The possibility of fast-cycling operation, thereby helping to avoid idle running and radiation losses.
- Toggle clamping, which is superior to fully hydraulic mould clamping from the energy point of view.
- Accumulator drive, superior to constant delivery pump operation from the energy point of view.

There is another conclusion we can draw from the above remarks. In many countries in the years to come, the main consideration in assessing energy problems will not be energy costs, but energy availability. Bearing in mind the shortage of energy, the problem of energy requirements must be regarded in an altogether different light. The losses a moulder may suffer because there is not enough energy to run additional machines, will provide just as much incentive to save energy as energy costs in themselves. It is likely therefore that, as far as the moulder is concerned, a reduction in energy requirements per machine will not mean reduced energy costs but rather be an incentive to increase production capacity.



Thermal insulating pad for the plasticising cylinder. Left: without insulation Right: with termal insulation

APPENDIX G.3.

HEATER BAND EFFICIENCY

1. Heater Band Efficiency
   Reproduced from Plastics Machinery and Equipment
   July 1982

2. Ceramic Bands Reduce Heating Costs
   T.W. McGwire,
   Industrial Heater Co., Inc.
   New York, N.Y.
   Reproduced from Plastics Machinery and Equipment
   July 1982

3. Mica vs Insulated Ceramic Heater Bands
   A. Gaudio
   Omega Heater Co., Inc.,
   Reproduced from Plastics Machinery and Equipment
   July 1982

4. The Effect of Insulated Shrouds on Heater Efficiency
   S.M. Klump
   Watlow Electric Mfg.,Co.,
   St. Louis, Mo.
   Reprinted from Plastics Machinery and Equipment
   July 1982

5. Energy Efficiency of Heater Bands in Injection Molding
   B.A. Olmsted, Manager
   Plastics Machinery Engineering
   Reed-Prentice Division, Package Machinery
   East Longmeadow, Mass.
   Reprinted from Plastics Machinery and Equipment
   February 1982

Heater-band efficiency:

Despite the fact that the energy consumed by barrel heater bands in injection molding is a relatively small portion of the overall energy consumption of the machine, reaction to a recent article on heater bands has been surprising.

In his article "Energy Efficiency of Heater Bands in Injection Molding" (see February 1982 PM&E p. 23), Bernie Olmsted of Reed-Prentice reported test results that brought into question the advantages of using insulated heater bands on the injection barrel.

At the heart of the controversy are test results that indicate that screw-drive energy consumption tends to increase when insulation reduces the consumption of the heater bands. Since the hydraulic screw drive consumes a greater portion of total machine power requirement, the overall savings that result from reduced heater consumption are minimal or nonexistent. Energy-consumption increases may, in fact, be experienced, Olmsted contends.

Other opinions on the performance of insulated ceramic heater bands are presented here. Several manufacturers of heater bands have done their own testing in cooperation with molders and molding-machine manufacturers. The results of these tests sometimes seem to contradict the Reed-Prentice findings.

There are some areas in which opinions coincide. There seems to be little doubt, for instance, that insulation on heater bands results in reduced electricity consumption by the bands. As noted, the disagreement arises over whether the reduction is matched by a corresponding increase in motor-drive energy consumption.

Many of those individuals who report energy savings say that watt-density patterns and temperature-control settings should be adjusted from those employed when uninsulated mica band heaters are tested. It appears that heat does build up in the barrel when insulated bands are used, and thermocouple signals result in shutoff of the heaters. But experts suggest that override can be avoided if temperature settings are adjusted properly and careful attention is paid to screw speed and backpressure.

Most also agreed on the value of using barrel covers or shrouds. The standard cover offered with most injection-molding machines is a 270-deg shroud around the barrel, although some original-equipment manufacturers offer optional 360-deg covers.

Covers can take the form of simple sheet-metal shapes with reflective interiors, or they can include a layer of insulation in addition to the air gap between heater bands and cover. Covers can develop an oven effect similar to that generated by insulated heater bands, and the same careful attention to temperature control is required.

Insulation blankets. A step beyond the barrel shrouds, insulation blankets that surround the barrel completely have begun to appear. A line of jackets is manufactured by Sav-A-Watt Inc., Riviera Beach, Fla. The units are constructed of 1-inch-thick spun-glass-fiber insulation with a glass-fiber-base inner covering and a silicone-coated outer covering.

The manufacturer reports that testing by customers has shown savings ranging from 20 to 50 percent of heater-band energy consumption. A 50 percent heater savings equals a savings of about 8 percent on total machine energy consumption, according to company spokesmen.

The same temperature-override potential exists, but it is suggested that the problem may be eliminated by using a steeper temperature profile through the zones.

Phil Eno, plant manager of Hoffer Plastics, South Elgin, Ill., says about 10 insulation blankets are installed in his plant. He estimates a savings of about 6 percent on overall machine energy consumption and has not experienced any heater-band failure related to their use.

The biggest savings, according to Eno, are savings in plant air-conditioning costs resulting from the reduced heating of air around the machine. Hoffer's entire plant is air conditioned, although the savings, while considerable, are difficult to calculate. The company expects to put the insulation blankets on the rest of its machines in the near future.

Extruded aluminum bands. Acra Electric, Schiller Park, Ill., manufactures a heater band that is said to provide efficient heat transfer due to its construction features. Available in 1½- and 3-inch widths, the bands incorporate heaters insulated with mica and sheathed in extruded aluminum.

The aluminum sheath is said to provide for excellent heat transfer when the band is clamped on the barrel, and its mass is said to yield more even heat distribution and energy retention for reduced cyclic stressing of the heater.

At Rubbermaid Inc., Wooster, Ohio, extensive testing has been performed to judge the efficiency of the extruded aluminum heaters. Engineers found a 34 percent saving was possible on heater-band energy consumption. This saving did not result in any increase in screw-drive energy consumption, and the company plans to install the bands on all machines as replacement of existing bands is required. Rubbermaid also plans to test the savings potential of the Sav-A-Watt insulation blanket.

As Tom McGwire of Industrial Heater Co. points out, the original insulated heater band was not developed for energy efficiency. The original goal was to reduce the release of heat around process equipment in the lab or shop environment. It was not until the energy crisis of the 1970s that energy savings became a consideration.

It should not be surprising then if savings do not accrue without altering the way in which machines are heated. Considering results achieved on tests using conventional mica heater bands with insulated shrouds, it should be fairly obvious that it is the insulation or barrel cover that saves energy—not the heater band itself. Likewise, the processor should not expect to save much energy without carefully analyzing his heating requirements and temperature-control settings.

According to Bernie Olmsted, "nothing is black and white." It is not possible to replace existing mica band heaters with ceramic heaters and achieve an energy savings every time. Such factors as screw design, part requirements, material characteristics, control settings and so forth all come into play. "There is a lot to this problem that doesn't meet the eye. In our testing, we looked for a simple way to save energy on heater bands and we couldn't find it," Olmsted admitted. But there are energy-cost savings to be had in injection molding, and it is up to the processor and the molding-machine manufacturer to come up with the best barrel-heating package to suit the particular application. ☐

Table I: Comparison of heater-band energy consumption

Machine	Cycle time, seconds	Material	Heater-band consumption, kw-hr Uninsulated heaters	Heaters with ¼-inch insul.	Heaters with ½-inch insul.	Savings, kw-hr per hr	Projected annual savings
Reed 200 ton	14.2	Polystyrene	2.87	1.66	1.32	1.55	$744, 6000 hr/yr at 0.08 kw-hr
Van Dorn 450 ton	54.9	Polypropylene	2.752	Not tested	1.766	0.98	$470.40, 6000 hr/yr at 0.08 kw-hr
Impco 700 ton	39.5	Polyethylene	20.98	Not tested	17.09	3.89	$1400, 6000 hr/yr at 0.06 kw-hr
Cincinnati 500 ton	4.57	Polyethylene	11.22	Not tested	8.43	2.79	$1339, 6000 hr/yr at 0.08 kw-hr
Cincinnati 375 ton		Polypropylene	2.281	Not tested	1.114	1.167	$630, 6000 hr/yr at 0.09 kw-hr

Table I: Energy efficiency of insulated ceramic vs mica heater bands

Product	Heating temperature, deg F	Processing temperature, deg F	Energy consumption for heating, kw-hr Mica bands	Insul. plus	Energy consumption during 1 hour processing, kw-hr Mica bands	Insul. plus	Heating time, min Mica bands	Insul. plus	Mass processed in 1 hour, gm Mica bands	Insul. plus	Energy* saving during processing, %
HDPE	(100)–450	450	0.50	0.69	0.84	0.80	11.9	13.2	672	720	4.8
	450–500	500	0.18	0.18	0.98	0.79	5.0	3.6	734	706	19.4
	500–550	550	0.16	0.20	1.04	0.87	3.7	4.2	646	635	16.3
PP	(100)–400	400	0.23	0.60	0.65	0.53	5.9	11.6	656	695	18.5
	400–450	450	0.17	0.27	0.74	0.53	4.8	4.9	541	593	28.4
	450–500	500	0.17	0.26	0.93	0.65	5.1	5.3	628	495	30.1

*No correction for the different masses processed.
Room temperature = 75F (24C)

Ceramic bands reduce heating costs

By Thomas McGwire, *Industrial Heater Co.*

The energy-saving potential of insulation in heater bands has recently become important, and tests have been conducted with heaters insulated with various thicknesses of insulation to achieve optimum savings on energy costs.

To demonstrate the benefits of insulated ceramic heater bands, Hycon Inc., Merrimack, N.H., tested bands with insulation thicknesses other than the standard ⅛ inch. Machines were tested for a minimum of 48 hours, using the same mold for consistency of results. Standard 270-deg barrel covers were in place for tests of both insulated and uninsulated heaters.

A standard watt-hour meter and an elapsed-time meter were used. Narrow (1 ½-inch) heaters were replaced with wider insulated heaters, covering as much of the barrel as possible. Total watt density was consistent or reduced up to 10 percent. Test results in Table I show consistent savings when bands with ½-inch insulation were compared with uninsulated bands. Savings averaged 37.4 percent of process heating costs. Total energy consumption of machines can be reduced 10 percent, it is estimated.

The larger machines showed the greatest potential for savings even though the throughput/hour was approximately the same. Wider insulated heater bands showed the greater savings when replacing numerous narrow uninsulated heaters because gaps between heaters were minimized. Ken Pedersen, chief engineer at Improved Machinery, consulted and supervised one test. "By any method of comparison the insulated ceramic bands showed considerable energy savings during the test," Pedersen commented.

All the machines tested by Hycon were manufactured prior to the energy crunch. Other results, from testing conducted by other manufacturers using new, energy-efficient machines with 360-deg barrel covers, may seem to indicate that band insulation thicker than ⅛-inch may contribute to greater energy consumption by the screw motor. It also appears that high shear under these conditions may lead to temperature override, but we feel such fluctuations, if they exist, could be solved through more efficient control of the front zones.

Barrel covers also assist in energy savings. The air gap between the cover and the barrel is an insulator and will prevent heat loss. The standard cover used to be 270 deg, but some machines now have 360-deg covers. Some machine builders feel that the 360-deg covers retain too much heat over the entire barrel and may cause temperature override in the front zones. Separators in covers between zones or separate covers for each zone eliminate this problem.

Insulation blankets strapped around the heaters also save energy. Blankets used with uninsulated heaters should not contact the heaters because hot spots, which affect heater life and cause melt-temperature problems, may result.

Other heaters are selected for good reasons. Mica heaters, for example, are very responsive. We, however, contend that the tests to date prove that insulated heaters are a worthwhile investment for energy-conscious processors. □

Mica vs insulated ceramic heater bands

By Al Gaudio, *Omega Heater Co. Inc.*

Because the insulated ceramic heater bands have operated reliably since the early 1950s, Omega theorized that building in more thermal insulation would reduce the amount of heat lost to the ambient air and the amount of energy required to do the work. Internal testing indicated that this theory was correct, and outside testing and actual field experience has been used to confirm the theory and account for the many variables involved in plastics processing.

Independent testing funded by Omega Heater Co. was done at the Polytechnic Institute of New York. The results, formulated from tests done on a lab-size machine, showed total machine energy savings of up to 30 percent by the use of thermally insulated ceramic bands. The data in Table I were published in 1979.

Tests at customers' plants reveal total machine energy savings that average 30 percent and sometimes reach as high as 40 percent; shroud temperatures were lowered by as much as 400 deg F; cycle times were shortened; and air-conditioning loads were reduced in some cases. The same general results have come from some of the largest molders in the plastics industry. After three divisions of a leading automobile manufacturer ran their own tests, involving many machines, materials, temperatures and other variables, hundreds of machines at eight plants were converted to the use of insulated bands.

Despite varying heater-band designs, there really is very little difference in how effectively heat is transferred. The insulated ceramic heater band has been tested and given an efficiency rating of 90.7 percent, compared to 87.2 percent efficiency in mica-insulated heater bands. These figures come from a study published in 1979 by a manufacturer of mica bands.

The fact is that no heater band—regardless of type—saves energy. Insulation and shrouding of a machine barrel save energy by reducing the heat lost to the ambient air. Shrouding a machine's barrel traps heat and creates an oven effect along the barrel, reducing energy loss. This is the object of insulated ceramic heaters with built-in thermal insulation. (Insulation should not be put over mica bands because the resulting excessive temperatures will reduce the operating life of the heaters.)

Any comparison between insulated ceramic heaters and mica heaters should take into account the fact that insulated ceramic heater bands, with higher-temperature capabilities and construction, have an average life span three to five times that of a mica band (all other conditions being equal). The life of ceramic bands is not affected by thermal insulation. Mica bands are most efficient in narrow widths, while ceramic bands are efficient in any practical width. For price comparisons, it can be assumed that one ceramic band will replace two or more mica bands. Fewer bands mean fewer electrical connections and less wiring.

Omega strongly suggests that processors test for energy savings in their own plants under normal operating conditions. Most power companies will assist in setting up simple tests. ☐

The effect of insulated shrouds on heater efficiency

By Steven M. Klump, *Watlow*

With the cooperation of Nypro Inc., a molder in Clinton, Mass., Watlow engineers conducted a series of field tests to better understand the effect of band heaters and barrel shrouds on overall machine efficiency. The tests were run in actual production to accurately measure the efficiency and overall performance of Watlow mica band heaters used with and without an insulated shroud, compared to that of individually insulated ceramic band heaters.

Some plastics molders have experienced temperature-control problems after converting to insulated ceramic band heaters in hopes of better efficiency. They experienced diminished product quality, increased cycle time and, in some cases, increased total machine consumption.

Watlow recommends the use of barrel covers or shrouds to improve the efficiency of injection-molding machines. Previous testing has shown this to be at least as effective as using individually insulated heaters. And it is less expensive. However, shrouds are not commonly used because they hinder normal machine maintenance.

After discussing the problem with Silvio Petrucci of Nypro, who has done much work on energy conservation in plastics molding, Watlow developed a barrel shroud that would provide heat efficiency while also allowing the desired accessibility for maintenance.

The prototype used in the tests was a full 360 deg with closed ends. It was made in four sections: a bottom half and three top sections. The bottom half was fixed to the barrel with split clamps. The top three sections (one over each heat zone) opened individually for easy access to the barrel. A mica-insulated wire trough was built into the shroud to route wires away from the barrel and to aid in installation.

Because it is important to determine the impact heater bands have on the total machine efficiency, we monitored the screw-drive motors as well as each heater zone.

The first series of tests (Table I) was conducted with mica band heaters with the watt density reduced by 32 percent. This derating is possible because of the shroud's efficiency. The lower watt density significantly extends heater life.

The machine tested was a 400-ton unit with 22-oz shot size. A general-purpose screw with an L/D of 20:1 and a compression ratio of 2.7:1 was used. ABS was processed at 76 lb/hour, using a cycle time of 61 seconds. Rear-zone setpoint was 380F, and middle and front zones were set at 420F. Watt density was 21.5w/sq inch in the rear zone, 16w/sq inch in the middle zone and 14w/sq inch in the front zone. A shroud was not used in the control test. All tests were conducted with the machine stabilized and producing good parts at the standard cycle time.

These tests proved the value of using the shroud for total machine efficiency. When the lower half of the shroud and the rear third of the

Table I: Comparison of mica bands with different shrouds

Barrel condition	Heater zone kw-hr Front	Middle	Rear	Total heater kw-hr	Change	Screw motor kw-hr	Change	Total kw-hr	Change
Mica bands without shroud	0	0.24	3.82	4.06	—	11.0	—	15.06	—
Mica bands with lower half and rear zone shrouded	0	0.4	2.29	2.69	-34%	10.96	—	13.65	-9.4%
Mica bands with lower half, rear and middle zones shrouded	0	0	2.38	2.38	-41.4%	11.0	—	13.38	-11.2%

Table II: Comparison of mica bands and ceramic bands

Barrel condition	Heater zone kw-hr Front	Middle	Rear	Total heater kw-hr	Change	Screw motor kw-hr	Change	Total kw-hr	Change
Mica bands without shroud	1.1	4.14	7.94	13.18	—	34.2	—	47.4	—
Mica bands with 360-deg insulated shroud, all zones (½-inch insulation)	0.28	2.56	6.6	9.44	-28.4%	34.3	—	43.7	-8.8%
Insulated ceramic bands (½-inch insulation)	0.736	3.38	6.28	10.40	-21%	35.5	+3.7%	45.9	-3.2%

top were installed, heater power consumption dropped 34 percent and motor consumption remained unchanged. The net result was a 9.4 percent improvement in total machine efficiency.

When the middle top section of the shroud was installed, the power required by the heaters again dropped significantly . . . down 41.4 percent from the control test. Again, there was no change in the screw-motor power consumption. The net result was an 11.2 percent improvement in total machine efficiency.

A second series of tests were used to measure the performance of this shroud/heater system compared to insulated ceramic heaters. All production variables were again held constant. The watt density of the insulated ceramic bands and the Watlow mica bands were identical and derated for insulation.

A 450-ton machine, with general-purpose screw (24:1 L/D and 3:1 compression ratio) ran 119 lb of polypropylene an hour. Shot size was 17 oz, and the cycle time was 32.4 seconds. Heat settings were 480F in the rear zone, 550F in the middle and 540F in the front. Heater watt density was 17w/sq inch in the rear zone and 10w/sq inch in the middle and front zones.

This test confirmed the effectiveness of using a 360-deg shroud (Table II). Energy requirements of the heaters fell by 28.4 percent, while the screw-motor consumption did not increase.

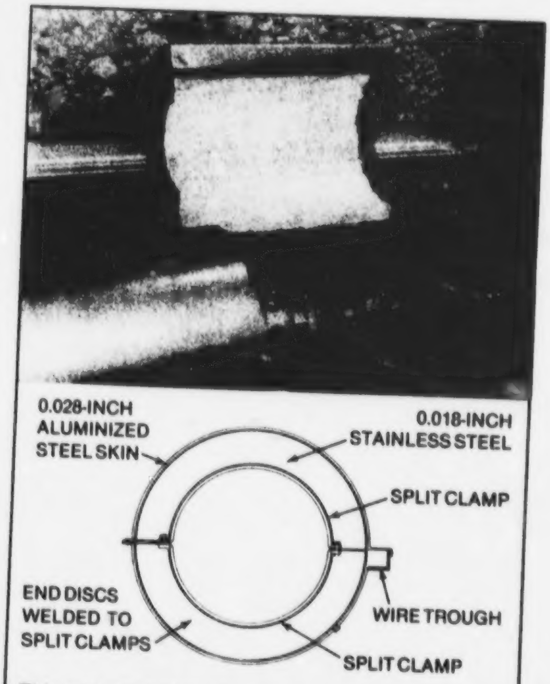
The test showed ceramic bands required slightly more in power compared to the mica-band/shroud system. It also showed an increase in screw-motor power usage.

The additional energy required by the motor apparently results from the lag in heat transfer through the high mass of the heavy ceramic heaters into the barrel. This delay is lengthened by the poor contact between the heater and the barrel.

When the thermocouple senses the proper temperature, the heaters are deenergized. However, heat in the mass of the ceramic heater cannot escape readily, due to the backside insulation. Therefore, it transfers into the barrel, causing melt temperature to rise in production.

The thermocouple will thus sense adequate heat in the barrel and not energize the heaters. With the heaters off, the screw must supply the heat required for plasticating through friction of the shearing of the resin. This is a far less efficient means of heat generation and causes the screw-drive motor to work beyond its most efficient load rating.

Mica band heaters are responsive due to their low mass and tight fit. They avoid the heat-transfer-delay effect. When used with a 360-deg closed-end shroud, they operate very efficiently. The shroud reduces heat losses and maintains an oven condition that modulates the heat for lower energy consumption and improved part quality. ☐


0.028-INCH ALUMINIZED STEEL SKIN
0.018-INCH STAINLESS STEEL
SPLIT CLAMP
END DISCS WELDED TO SPLIT CLAMPS
WIRE TROUGH
SPLIT CLAMP

This prototype shroud was developed by Watlow for use in the series of tests on heater bands.

Energy efficiency of heater bands in injection molding

By Bernie A. Olmsted,
Reed-Prentice Div., Package Machinery

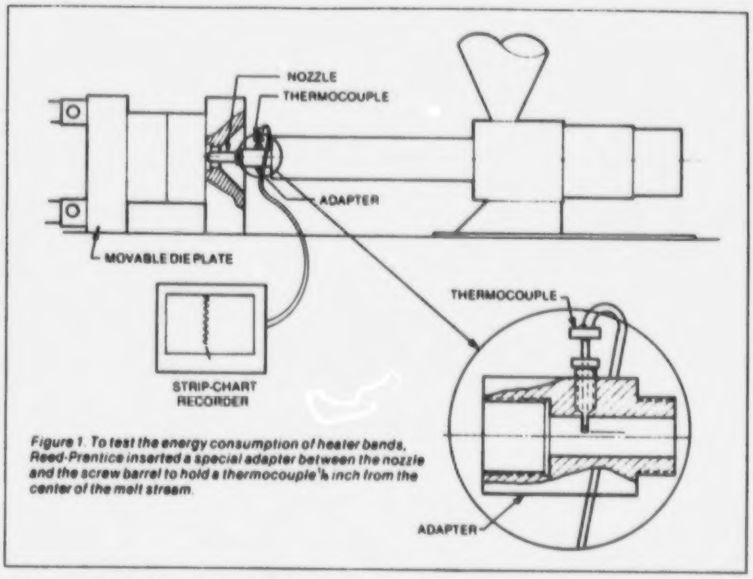


Figure 1. To test the energy consumption of heater bands, Reed-Prentice inserted a special adapter between the nozzle and the screw barrel to hold a thermocouple ⅛ inch from the center of the melt stream.

Two years ago, Reed-Prentice introduced its TG series of molding machines, which were designed specifically for their energy efficiency. At the time, ceramic heater bands were just beginning to get publicity as energy savers. Ceramic heater bands were not new; they had been available and had been used by the industry from back in the early '50s.

But the new generation of ceramic bands being promoted at the time the TG series was introduced were equipped with a ½-inch-thick layer of insulation between the heater elements and the cover. Because of an interest in energy savings, Reed-Prentice began testing to determine if there was a valid claim to energy savings with the use of ceramic heater bands. In order to provide the best operating machine possible with the lowest energy consumption, Reed also investigated the effect of the use of blankets, the wrapping of barrels and the use of covers.

TEST CONDITIONS

In order to test the various heater bands and other combinations of covers and blankets, a baseline was first established. A Model 250 G 20-oz injection-molding machine with a 20:1 L/D screw was used. The mold was a two-cavity tool for producing an ABS savings bank.

The machine was equipped with a special adapter between the nozzle and the screw barrel, which was designed to hold a thermocouple ⅛ inch from the center of the melt stream (Figure 1). The machine cycle was maintained at a constant rate, and the only change made from one test to another was in the heat profile, which was regulated to maintain a target temperature in the melt (unless otherwise specified).

The melt thermocouple was attached to a strip-chart recorder to verify the melt temperature and to ensure a constant condition. The strip chart traces the melt data (Figure 2). Tests were not run until the trace was consistent, cycle to cycle.

Two meters were used to record the energy consumed. One was connected to the drive-motor system and the other to the barrel-heater system. Both readings are required because the drive-motor load can change, depending on the amount of heat generated into the plastics by shear.

The target temperature was set at 445F at the low point, with a rise to 480F during injection. The rise in temperature is due to the shear of the plastics across the thermocouple junction. The control run, test H-1, established the conditions for cycle time, pressures and other parameters. A few surprising results were shown in the tests.

TEST RESULTS

In tests for energy efficiency (Table I), many factors must be considered—thermal-energy consumption, overall energy consumption and the effect of the heat on the melt, which affects overall part integrity.

Heater covers are necessary to conserve energy. As shown in test H-2, removing the heater cover has a dramatic effect on energy consumption. Heaters without covers require 43 percent more energy to accomplish the same task. Note, however, that the amount of energy required to heat the barrel is only 18 to 25 percent of the energy used to drive the hydraulic pumps, making the energy consumption used by the pumps a much more significant factor in overall energy consumption.

In test H-4A a different heat profile was used on the heater zones to prevent the heater zone from overriding the setpoint and to maintain target temperature, resulting in a thermal-energy-consumption increase of 21 percent. But here again, since the resulting motor-power consumption—the major factor—was reduced by 2 percent, the overall energy consumption was not significantly affected. It was noted in this test that it takes longer for a barrel with ceramic heaters to stabilize than for a barrel with mica heaters to stabilize. In the control test, it took only 20 minutes from the time the heat was turned on to run the job. The ceramic heater with ½-inch insulation in test H-4A required 80 minutes to stabilize.

Overall energy consumption was most favorable in test H-5, in which the special heat profile was omitted and the same heat profile was used as in the control test. This, however, did permit temperature-setpoint override in the heater zones in the front and the center, which resulted in a 15-deg-F rise in temperature over the target. A fluctuation in melt temperature also resulted, raising and lowering in a 10-deg-F wave-like pattern. This condition had been noticed in several customers' plants where ceramic bands were in use. The temperature wave allows the viscosity of the melt to change and causes part imperfections varying from slight sinks to light flashing.

It was theorized that the insulation over the bands was creating a heat-sink condition. This happens because the watt density of the heater bands is usually determined by the need for heat at startup. Once the barrel has heated up, the bands need to supply the heat required to main-

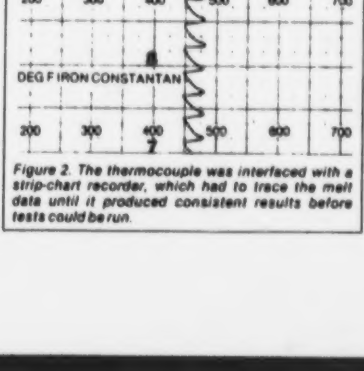
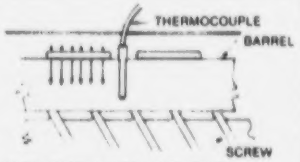


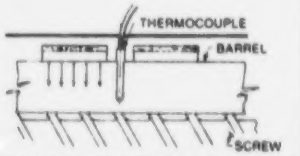
Figure 2. The thermocouple was interfaced with a strip-chart recorder, which had to trace the melt data until it produced consistent results before tests could be run.

Table I. Comparison of heater-band vs motor energy consumption

Test	Conditions	Motor kwhr	Heater kwhr	Total kwhr
H-1	Mica bands, standard 360-deg cover	23.1	4.05	27.19
H-2	Mica bands, cover removed	23.6 +2%	5.8 +43%	29.42 +8%
H-4A	Ceramic bands, ½" insulation, different heat profile	22.6 −2%	4.9 +21%	27.57 +1%
H-5	Ceramic bands, ½" insulation, same heat profile as H-1	20.8 −10%	4.64 +14.5%	25.4 −6.6%
H-1C	Mica bands, full cover, insulation blanket over cover	28.5 +23%	2.3 −43%	30.8 +13%
H-1D	Mica bands, no cover, insulation blanket over heater bands	34.7 +50%	.99 −75.5%	35.7 +31%
H-10	Ceramic bands, ½" insulation, same heat profile as H-1	35.99 +55.8%	1.06 −73.8%	37.05 +36%



MICA HEATER BANDS · WITH COVER



CERAMIC HEATER BANDS · WITH ⅛ INCH INSULATION

Figure 3. Heater bands with a cover (top) trap heat between the band and the cover and act like an oven. Insulated bands force the extra heat down into the barrel, which causes an override condition

tain a set temperature and to also make up for heat removed by the melt as it moves along the barrel. This accounts for consumption of only approximately 25 percent of the wattage available as an average. But when heat is called for by the thermocouple, the heater band emits heat at full strength. Depending on heat-control instruments and how they are balanced, a heat level higher than that called for by the thermocouple is provided at the surface under the band.

When this condition occurs with uninsulated bands, a certain percentage of the heat is radiated away from the outside of the band. Without a heater cover, it is lost and wasted as in H-2. However, with the full cover (Figure 3) heat is trapped and the space between the bands and the cover acts as an oven, modulating the heat and eliminating a high override of heat at the surface. The result is a consistent heat input to the melt that maintains a constant melt temperature. Variations in the on/off cycle of the control can occur and produce a wave effect, but only if the control is not tuned in properly.

The insulation on ceramic heater bands prevents heat from radiating into the atmosphere, so the extra heat provided by the band over and above that required has nowhere to go but into the barrel. When the thermocouple reads that enough heat has come down into the barrel, a high level of heat is still left at the surface of the barrel and will continue down through the steel into the melt even after the thermocouple transmits the signal for heat to be cut off. This causes fluctuations in melt temperature that affect the viscosity of some resins. The problem is readily apparent in jobs where a temperature-override condition exists like that experienced with the use of ceramic insulated bands or any other type of insulation.

To further explore the effects of too much heat being transmitted, tests were conducted with an insulation blanket that covered the whole barrel. In test H-1C, the blanket was wrapped over the full cover of a standard machine with mica bands. The thermal-energy consumption was reduced, but the motor-energy consumption increased, resulting in an overall energy-consumption increase of 13 percent. In test H-1D, the blanket was wrapped directly around the mica heater bands of a standard machine. Again, thermal-energy consumption was reduced even more, while motor consumption increased dramatically, resulting in the total energy-consumption increasing by 31 percent.

The results of the tests indicated that whenever insulation was put over the bands, in any form, machine-drive energy consumption increased. Since this did not seem to make sense, another test was conducted in which the screw-drive pressure in a machine with insulated ceramic heater bands was compared to the screw-drive pressure of the control test. This test confirmed the results of the previous two tests. It was found that the trapped heat in the steel, which causes heater-zone override, causes the thermocouple to read that additional heat is not needed. The screw, therefore, takes over and provides the necessary heat by shear, causing the melt temperature to increase by about 15 deg F and using more energy than any of the other test runs. The conclusion drawn from these last three tests is that, although insulation may reduce thermal-energy consumption, it has an adverse effect on overall energy consumption.

Recognizing the need to cool down the cover where air conditioning is used in the plant, Reed-Prentice ran one more test where ⅛-inch insulation material was fastened to the inside surface of the cover. The test showed a 12 percent increase in energy required. But it appears that the insulation is the best solution to date to meet the needs of those plants with air conditioners.

The conclusion drawn by Reed-Prentice is that at present uninsulated heater bands with a full cover seem to be the most efficient system. It is strongly recommended that the cover have a shiny inside surface and be kept in place at all times. Removing the cover and replacing it with insulated bands is not a satisfactory solution—particularly if molding tolerances are critical and melt control is important. Not only does this system use less energy, but it provides a more stable melt viscosity, which affects molding conditions, part quality and cycle time.

Testing of the thermal-energy consumption alone without testing the drive energy can lead to some very misleading conclusions. This is particularly true if heat zones are overriding the set-point and the energy is being replaced by the drive system—an expensive trade-off. ☐

APPENDIX G.4.

HEATERLESS NOZZLES

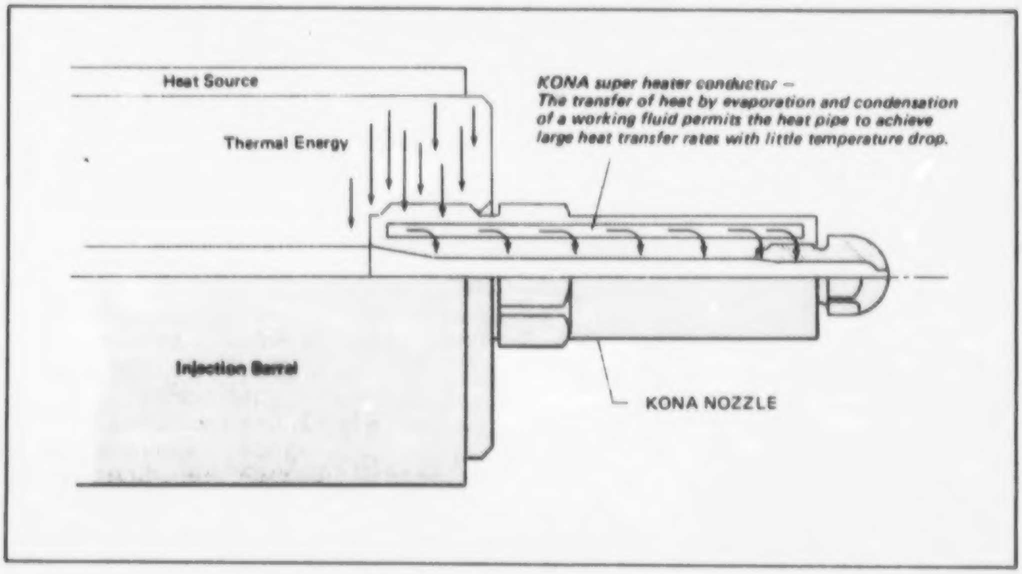
This literature is supplied to assist the molder but its inclusion here does not constitute any endorsement.

1. Kona Corporation
   Plastics Machinery Inc.,
   Markham, Ontario

KONA NOZZLE

(Heaterless Injection Molding Nozzle)

The KONA NOZZLE is characterized by the absence of a heater band requirement on the main barrel of the nozzle. Most styles of the KONA NOZZLE are completely heaterless, others such as X-TRA LONG styles require a booster heater at the back (machine end) only. This remarkable feature is made possible by the application of "heat pipe" technology which has the characteristic of being able to transmit thermal energy at near isothermal conditions. The thermal energy required to operate the KONA NOZZLE is conducted directly from the barrel of the injection molding machine, thereby assuring the nozzle will always operate at precisely the correct processing temperature.



KONA super heater conductor — The transfer of heat by evaporation and condensation of a working fluid permits the heat pipe to achieve large heat transfer rates with little temperature drop.

KONA NOZZLE is:

SAFE, Since heater bands are not used or are removed from the mold area, the KONA NOZZLE eliminates electrical hazards normally associated with conventional injection molding nozzles. For this reason, KONA nozzles should be used on all injection molding machines by safety-conscious plastic processors.

COST EFFECTIVE, Payback on the investment of converting to heaterless nozzles is truly outstanding. Of the several cost savings features of the KONA NOZZLE, the *elimination* of downtime due to *heater burnout* is the most dramatic. One downtime per week per machine due to nozzle heater failure is not uncommon and, in fact, may be conservative on some machines. The second direct savings, which alone easily justifies KONA NOZZLE use, is the ongoing cost of replacement heaters, thermocouples and controllers. The annual cost of replacement heaters alone is commonly greater than that of one KONA NOZZLE. Additional savings are realized from reduced power requirements because the KONA NOZZLE radiates less heat energy than conventional nozzles.

A BETTER NOZZLE, KONA NOZZLE always *automatically* operates at the optimum processing temperature; never too hot, never too cold. Because the KONA NOZZLE is a super conductor of thermal energy it is nearly isothermal, and therefore eliminates the temperature gradients that cause process variables.

KONA NOZZLE is a trademark of KONA Corporation and is covered under U S Patent Number 4 034 952 and other foreign patents Other patents pending Copyright KONA Corporation 1980 Printed in U S A

APPENDIX H.1.

Articles on Extrusion Machine Design and Efficiency

1. Extruder Efficiency: How You Measure It - How You Get It.
   G.A. Kruder and R.E. Nunn
   HPM Corporation
   Mount Gilead, Ohio

2. How Screw Wear Affects Extruder Performance and What It Costs.
   D.C. Lounsbury
   Davis-Standard Division, Crompton & Knowles Corp.,
   Pawcatuck, Conn.
   Reproduced from Plastics Engineering
   September 1982
   Presented at Society of Plastics Engineers Technical Conference
   May 1982

3. Optimizing Energy Utilization in Extrusion Processing
   G.A. Kruder and R.E. Nunn
   HPM Corporation,
   Mount Gilead, Ohio
   Presented at Society of Plastics Engineers Technical Conference
   May 1981

Extruder efficiency: how you measure it—how you get it

Drive-power economy, as a measure of extruder efficiency, is misleading. The concept favors operation at slow speeds, when a look at the total energy picture shows that efficiency lies in operating at maximum speeds. Greatest efficiency comes from driving a full load as well.

George A. Kruder
R.E. Nunn
HPM Corp., Mt. Gilead, Ohio

Despite what you've been hearing or reading, if you were to analyze the energy efficiency of an extruder in a typical commercial operation (considering all energy-loss points, as shown in *Fig. 1*), you would find relatively little waste. Most extruders operate between 45 and 75 percent overall efficiency.

The most common measure of extruder efficiency, drive-power economy (pounds per hour per horsepower), is accurate only when the extruder is operated adiabatically and under ideal conditions—full load and maximum dc motor speed. The problem is that drive-power economy criteria suggest that low screw speeds are most efficient. But low screw speeds generate less shear heating, which must be supplemented by barrel heating—an energy input drive-power economy figures ignore. Low screw speeds also make the least-efficient use of the dc motor drive, unless it is geared to operate at or near maximum speed to keep the displacement power factor near unity.

Energy distribution

A breakdown of total energy inputs and losses in an extruder (see *Fig. 2*) shows the importance of making efficient use of the dc drive and of barrel heating and cooling. Of the total energy loss of 39.2 percent, fully 30 percentage points, or about three-quarters, is lost there. Therefore, no matter how high the drive-power economy rating, if waste from these areas is not minimized, the extruder cannot be operating efficiently.

A better gage of extruder efficiency is the "energy balance" approach to polymer processing. Here, the theoretical horsepower required for melting, P_T, is compared with actual horsepower consumed. P_T can be calculated as follows:

$$P_T = \dot{m}\int_{T_1}^{T_2} C_p dT + \dot{m}\nu\Delta p$$

where $\dot{m}$ = mass flow rate of polymer, T_1 and T_2 = screw inlet and discharge temperature, respectively, C_p = specific heat capacity of polymer, ν = specific volume of polymer melt, and Δp = screw discharge pressure. The equation represents the power required for melt preparation ($\dot{m}\int_{T_1}^{T_2} C_p dT$) and the power required for forming through the die ($\dot{m}\nu\Delta p$). The latter is usually less than 5 percent of the total. Overall energy efficiency is then found by dividing the theoretical horsepower consumed by the actual horsepower needed for processing. Actual horsepower can be calculated from measured dc amperes using this equation: (The 0.9 is a factor related to motor efficiency; no motor is ever 100 percent efficient)

$$\text{Actual horsepower} = \frac{\dfrac{\text{Measured speed}}{\text{Maximum rated speed}} \times \text{Maximum armature voltage} \times \text{Measured dc amperes}}{746} \times 0.9$$

In search of efficiency

Many years ago pioneer investigators J. M. McKelvey, E. C. Bernhardt, and B. H. Maddock showed how to theoretically determine from feedstock and extrudate the minimum amount of energy needed to operate an extruder. Efficiency has always been an important goal in engineering circles, and remains such, but, of course, in these days of significantly higher energy costs, it has found additional boosters in many different quarters, as well.

The recent clamor for efficiency, however, has helped focus attention on the efficiency of existing machinery, and engineers have responded in the way they know best—with facts and figures, and an equation or two. The authors of the present article began to make the case for extruder efficiency in a NATEC paper last year. (The study also included injection-molding machines.) In the current article, these earlier insights are further refined and updated.—The Editors.

maximum screw speeds but at less than maximum loads, dc motors waste much energy. However, under favorable operating conditions—maximum loads—dc motor drives are efficient, as shown in the extrusion of high-density polyethylene with a fully loaded lighter-duty 50-horsepower extruder. Under these conditions, overall efficiencies reached a respectable 75

Screw design

An extruder cannot begin to approach maximum efficiency if operated with a poorly designed screw. The wrong screw can lead to inadequate shear heating or even drastically overheated melt unless operated at low speeds or with excessive barrel and screw cooling.

In the analysis of extruder efficiency, we tested two other screws—Max Melt and conventional screws—with the 75-horsepower extruder. Like the double-wave screw, the Max Melt gave highly uniform melt quality with polyethylene. The energy efficiency was slightly lower at low discharge pressure, yet slightly superior at high discharge pressure. (Polystyrene showed little difference in efficiency for all screws.)

The conventional screw yielded lower energy efficiency and exceptionally poor melt quality for low-density polyethylene at the highest screw speed (175 rpm), and yet this screw is typically used for polyethylene with a melt index of 2. The same results were found for high-impact polystyrene at high speeds on the conventional screw. □

Test details

Processing was performed with 2.5-inch, 30-to-1 heavy-duty 75-horsepower extruder and a lighter-duty 50-horsepower air-cooled extruder. The latter was used for testing efficiency under fully loaded conditions.

Temperatures and pressure fluctuations in the die adapter were monitored using a Hewlett-Packard eight-channel oscillograph recorder; five channels were devoted to monitoring time on and off for water cooling and electrical heating of each barrel zone. Most other data came directly from the extruder control panel, an ac recording wattmeter, and direct measurement of screw speed and output.

Polymers processed with the 75-horsepower extruder were Union Carbide type DYNH (2 melt index) polyethylene and Cosden 825E sheet-grade impact polystyrene. In the lighter-duty extruder, Phillips TR800 high-density polyethylene was used.

Overall efficiencies reported in the *Table* were based on the calculated value of theoretical horsepower requirement, which assumed that the exit melt temperature was the ideal melt temperature. Obviously, this was not always the case. Often, improved melt mixing affects product quality more than the average temperature at the screw tip, making it possible to save energy by lowering melt temperature. However, most melt temperatures recorded in the *Table* were typical of commercial applications. For that reason, calculated overall efficiencies can be expected to be typical.

Energy efficiency of extruders processing polystyrene and polyethylene using double-wave screws.

Resin	Screw speed, rpm	Output, pounds per hour	Exit melt		Nominal barrel temperature, °F		Dc-drive horsepower
					Zone		
			Temperature, °F	Pressure, psi	1	2 to 5	
High-impact polystyrene[a]	50	124	454	670	400	450	7.7
	100	217	474	850	400	450	16.7
	100	220	447	1020	374	365-397[c]	19.0
	100	180	483	1975[d]	400	450	14.5
	176	284	493	2610[d]	325	400	29.9
	176	325	465	1470	325	400	32.2
	176	305	481	900	400	450	27.3
	176	320	468	1075	415	360-407[c]	31.4
Low-density polyethylene[a]	52	97	349	1020	300	325	6.5
	99	189	355	1320	300	325	15.8
	99	189	334	1420	268	278-291[c]	17.9
	100	189	357	1300	275	300	15.3
	100	142	374	3500[d]	275	300	14.9
	170	326	360	1610	304	289-317[c]	34.2
	170	326	368	1550	300	325	34.1
	175	242	392	4400[d]	275	300	30.5
High-density polyethylene[e]	100	192	395	700	300	330	21.2
	150	303	368	1000	300	330	36.1
	200	370	386	1050	300	330	51.7

[a] 75-horsepower heavy-duty extruder

[b] Theoretical horsepower divided by actual horsepower

[c] Processed adiabatically

[d] Valved to a higher pressure

[e] 50-horsepower lighter-duty air-cooled extruder

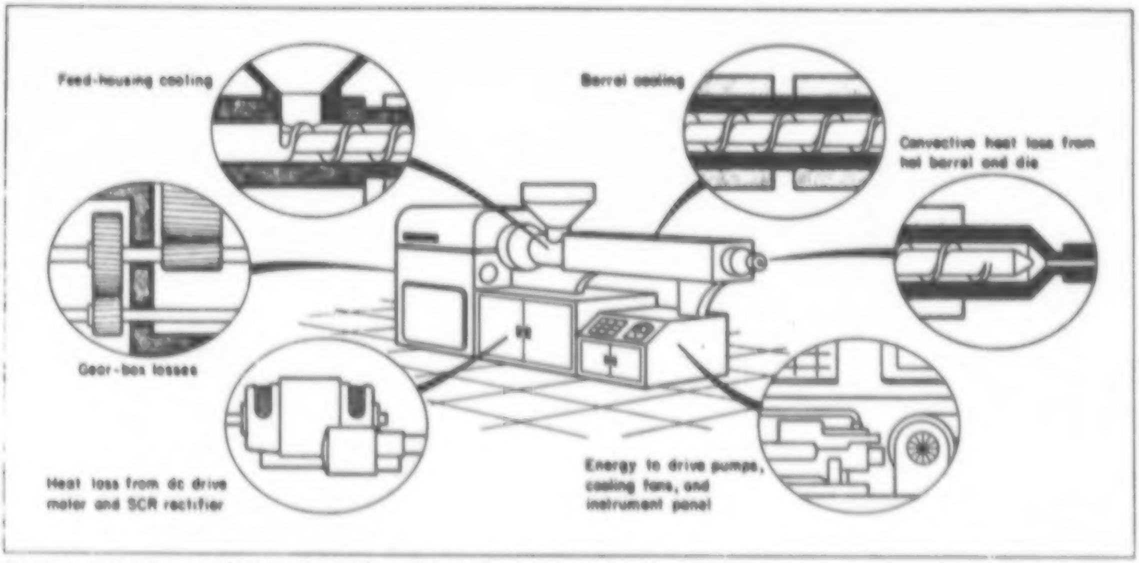

Feed-housing cooling
Barrel cooling
Convective heat loss from hot barrel and die
Gear-box losses
Heat loss from dc drive motor and SCR rectifier
Energy to drive pumps, cooling fans, and instrument panel

Figure 1. Areas of energy loss in an extruder using no screw cooling or venting.

Drive-power economy versus overall efficiency

To demonstrate the inadequacy of drive-power economy as an efficiency yardstick, we processed two resins (low-density polyethylene and high-impact polystyrene) at various screw speeds and pressures, running adiabatically and nonadiabatically.

We found that for both resins, overall efficiency (theoretical horsepower divided by actual horsepower) is lowest at low screw speeds, even though drive-power economy is highest (see *Table*). As mentioned earlier, at low screw speeds, a considerable portion of the melt energy input comes from the barrel heaters. The energy consumption of additional heating and cooling is also shown in the *Table* in the four instances where the resins were processed adiabatically. Overall efficiency was consistently higher—as much as 5 percent at one screw speed for polystyrene—when no additional heating or cooling was applied.

An area of greater potential energy waste is the dc motor drive. The large gap in efficiency between processing at 50 and 170 rpm (as much as 20 percent) is not simply due to the need for supplementary heating at slow screw speeds. Even when operated at

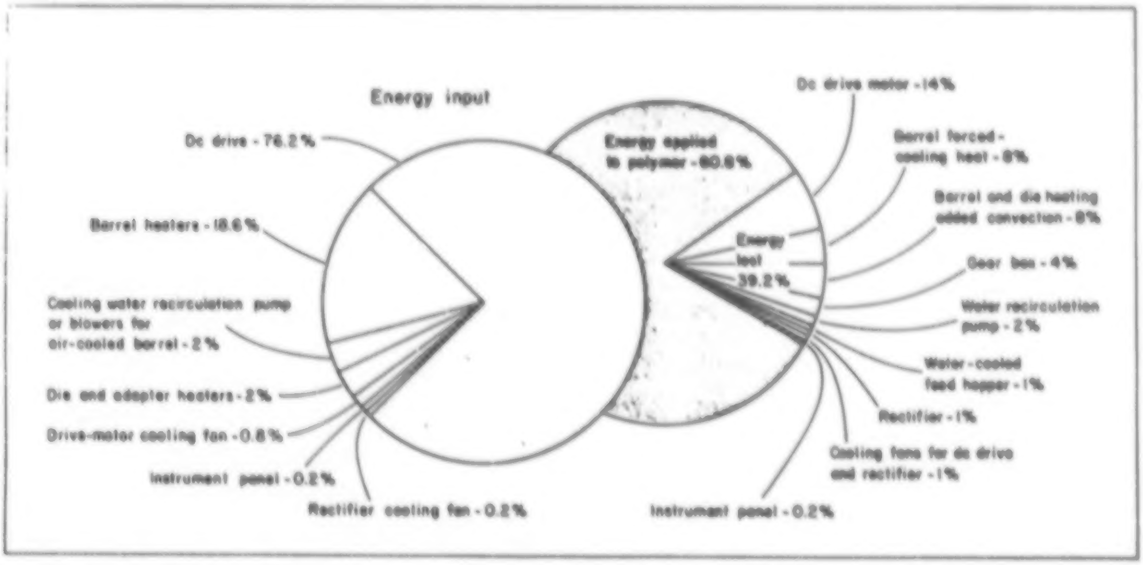


Figure 2. If an extruder is to run efficiently, energy losses must be minimized in the dc motor drive and in barrel heating and cooling—the largest areas of energy transfer.

percent.

When the motor is operating at less than full load and maximum speed, efficiency drops significantly. For example, a 60-horsepower dc drive operating at full load and full speed—virtually ideal operating parameters—has an overall efficiency of 86.9 percent (with 1 percent rectifier loss). Efficiency falls slightly, to 83 percent, at one-half load, but plummets to 70 percent at one-fifth load.

Efficiency drops even more quickly as motor speed decreases. For one thing, since total rectifier and motor losses are not strongly affected by motor speed, the ratio of effective power to lost power decreases at low speeds. For another, low speeds dramatically reduce the displacement power factor. At one-third speed, the power factor of the drive motor is only 26 percent; at three-quarter speed, 60 percent; at full speed, 84 percent.

Given the choice, it is more economical to operate at half load and full speed rather than at half speed and full load. Therefore, if you buy a more-powerful drive either to process more-difficult materials or to increase production, the extruder should be geared to operate at close to maximum dc motor speed with provisions to change screw speeds as needed. □

The cost of inefficiency

The actual cost penalty for inefficient processing ultimately depends on the size of your operation and the cost of electricity. A small-scale operation located in a low-cost power area may be able to tolerate a substantial degree of energy waste. Wasting 10 horsepower at 3 cents per kilowatt-hour would add only about 20 cents an hour to costs (neglecting power factor penalties).

On the other hand, running several small extruders or a few large ones inefficiently can add thousands of dollars to annual operating costs, especially where high utility rates apply. For example, six 4.5-inch heavily loaded extruders operating simultaneously might consume 1000 kilowatts. At an average operation of 6000 hours per year and at 6 cents per kilowatt-hour, the annual electric bill would be $360,000. Obviously, a 10-percent reduction in energy use would be worthwhile to pursue.

In one such plant in the Midwest, a reduction in power factor from 96.2 to 80 percent would add almost 12 percent to the electric bill. □

Drive-power economy, pounds per hour per horsepower	Measured total power, horsepower equivalent	Overall power economy, pounds per hour per horsepower	Theoretical required horsepower, (P_t)	Overall efficiency, percent[a]
16.1	23.1	5.4	8.1	35.1
13.0	30.7	7.1	15.1	49.2
11.6	26.8	8.2	14.1	53.0
12.4	28.6	6.3	13.1	45.8
9.5	44.2	6.4	21.4	48.4
10.1	44.5	7.3	22.2	49.9
11.2	45.2	6.7	21.7	48.0
10.2	40.2	8.0	22.0	54.7
15.0	18.4	5.3	8.5	46.3
12.0	28.5	6.6	17.1	60.0
10.5	25.6	7.4	16.0	62.5
12.4	26.5	7.1	17.1	64.5
9.5	26.0	5.5	13.9	53.3
9.5	43.7	7.5	29.8	68.2
9.9	45.2	7.2	30.5	67.5
7.9	44.1	5.5	25.1	56.9
9.1	29.1	6.6	22.1	75.7
8.4	45.5	6.7	33.1	72.7
7.2	59.4	6.2	42.3	71.7

How screw wear affects extruder performance and what it costs

Screw wear can result in a serious profit drain and the "percentage rule" often understates its adverse effects. Therefore the processor must establish benchmark conditions and run them periodically to keep track of the effects of wear on his process.

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We all know that screws and barrels wear. We realize that wear varies with different resins and additives, and under different operating conditions. We intuitively feel that output is reduced as screws wear. The missing segments in our knowledge are: the relationship between wear and output loss; the potential for other deleterious effects accompanying wear, and (probably most important) when it is economically sound to replace or rebuild a screw. This article attempts to give guidelines toward these goals.

Theories have been advanced over the years to find a method to relate screw wear directly to its effects on performance and costs. Maddock[a] related output loss to the clearance expressed as a percent of metering depth (percentage rule). Barr and Chung[b] described experimental work and noted complicating interrelationships between viscosity, shear rate, temperature, melt-to-barrel adhesive forces, and non-contact shear wiping. Klein[c] reported on extensive predictions of the effects of wear all by a computer simulation. Building on these foundations, we have tried to provide a broader data base for field production line situations by:

- Studying the processing of two polymers with widely different viscosities.
- Examining a wide range of screw speeds.
- Simulating four fixed die constants ranging from the minimum restrictions of a compounding application through fiber, sheet, wire and cable, and up to the relatively high die restrictions of a blown-film application.
- Running a Maddock screw, perhaps the most common screw in the field today.
- Simulating wear in the transition and first metering section of the screw. (This parallels the bulk of Davis-Standard's experience in screw rebuilding.)

Experimental work

The experimetal work was conducted in the Davis-Standard Laboratory on a 2-1/2-inch, 24:1 extruder with the proper temperature control system selected for rapid response and excellent temperature stability. The melt was pumped through a valved adaptor, having an index plate so that four fixed valve positions, or die constants, could be accurately repeated. Pressure along the barrel and at the breaker plate, plus melt temperature, were recorded on an eight-channel Hewlett-Packard recorder. The drive speed (rpm), drive voltage and current (from which horsepower are derived) were read digitally.

The experimental program centered on the screw. It was manufactured as a 0.150-inch-deep Maddock screw as shown in *Fig. 1*. Since this was a research investigation, the screw was initially manufactured at 1/2 of the nor-

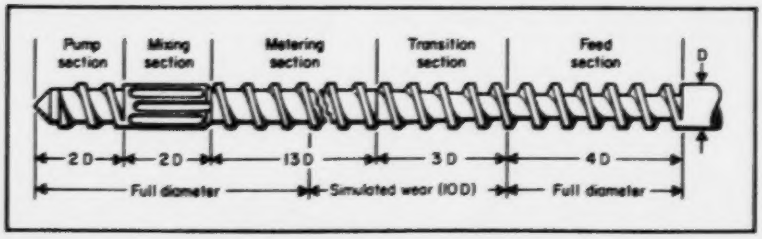

Figure 1. Test screw was manufactured with 1/2 normal clearance. Screw was ground in steps, each step followed by tests. After full-length grinding to standard clearance, successive cuts were made in the wear area only.

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[a] Maddock, B.H., Effect of wear on the delivery capacity of extruder screws, SPE Journal, May, 1959, page 433.

[b] Barr, R.A. & Chung, C.I., Effects of radial clearance on extruder performance, SPE Journal, June, 1966, page 71.

[c] Klein, I., the effect of flight clearance on the performance of plasticating extruders, ANTEX XX, 1974, page 237.

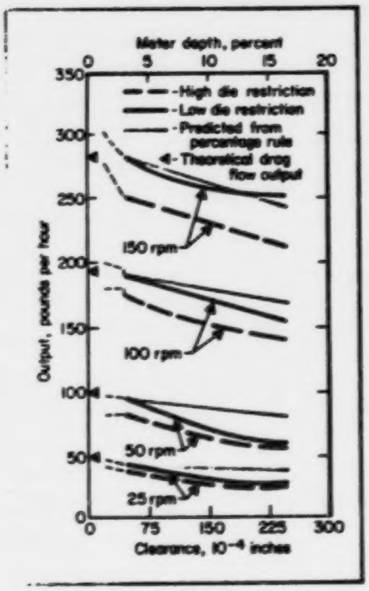

Figure 2. High-viscosity polymer (high-density polyethylene) was tested for output as a function of clearance.

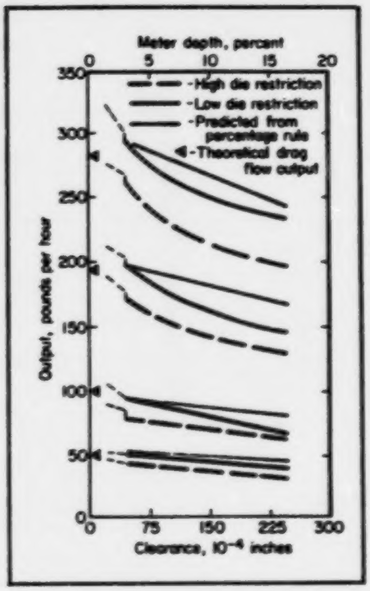

Figure 3. Low-viscosity polymer (low-density polyethylene) tests show output versus clearance at different speeds.

mal practical commercial clearance over its full length. The screw was tested at this 1/2 nominal clearance, then ground in the wear area only (see *Fig. 1*) to standard clearance, and tested again. It was then ground full length to standard clearance and tested. It was successively ground and tested in the simulated wear area only, in steps, until it had been ground to 0.025-inch (17 percent of meter depth) clearance. The rest of the screw other than the area designated as simulated wear area was left at normal commercial clearance. The steps examined were nominally 0.0015-inch (1 percent), 0.0035-inch (2 percent) or "normal commercial clearance," 0.007 inch (5 percent), 0.015-inch (10 percent), and 0.025-inch (17 percent) of metering depth clearance. Two polymers were run at each grind, or test: a high-viscosity material, high-density polyethylene with 0.3 melt index;[d] and a low-viscosity material, low-density polyethylene with 2.0 melt index.[e] The viscosities of these two materials are an order of magnitude apart. Four screw speeds were run on each polymer: 25, 50, 100, and 150 rpm. At each screw speed four valve positions simulating the four die-restriction levels were run. Thus a total of 32 tests were run at each grind or clearance step.

Two things should be noted for clarity. First, the definition of clearance is a radial clearance. That assumes a centrally located screw; therefore the clearance equals half the difference in diameter between the screw and the barrel. Second, while our procedure simulated screw wear only, we feel clearance is the prime factor, and any barrel wear would also contribute to loss of performance.

Typical results of screw-wear tests.

	Stable		Unstable		Stable	
	LDPE at 25 RPM		HDPE at 25 RPM		HDPE at 150 RPM	
Clearance, inch	Output, pounds per hour	Pressure variation, percent	Output, pound per hour	Pressure variation, percent	Output, pounds per hour	Pressure variation, percent
0.0015	50	0.65	45	0.55	300	2.0
0.0035	49	1.0	44	0.58	289	1.2
0.007	46	0.95	39	0.63	276	0.8
0.015	42	1.0	30	15	263	0.7
0.025	39	0.83	24	16	249	1.0

Output

Prior work had led to the expectation that output falloff would be equal to clearance, expressed as a percentage of the meter depth, referred to as the percentage rule throughout this article. *Figure 2* represents the results obtained on the high-viscosity material (high-density polyethylene). The colored lines are reference lines—they are predictions from the percentage rule that output fall-off equals the clearance expressed as a percent of metering depth. They start at the point of normal commercial clearance. Only the high- and low-die-restriction curves were shown for each speed for clarity. The intermediate curves fell in between and assumed the same general shape. The percentage rule can be seen to understate the output loss (output fall-off) compared to the real situation by as much as 2-1/2 times at the low screw speeds. The percentage rule is a reasonable estimate at high speeds.

Results on the low-viscosity material are shown in *Fig. 3*. On this material the percentage rule provides a reasonable estimation of output loss at low speeds; however, it materially understates output loss at high speeds.

Extrusion stability

Figure 4 is atypical recording of relatively stable extrusions. With the recorder gains turned up as they were, this represents only a 1-percent pressure fluctuation. Wear caused no significant effects on stability through the 0.007-inch (5-percent) grind under any operating conditions. Under 3/4 of the operating conditions of resin and speed, no significant effects were apparent throughout the entire program, i.e., through 0.025-inch (17-percent) clearance. However, at 0.015-inch (10-percent) clearance level, disastrously poor stability was experienced on the high-viscosity polymer only, at 25 and 50 rpm only. This was labeled a "zone of instability."

One might expect that proceeding from the 0.15-inch (17-percent) grind the "zone of instability" would broaden. This did not occur. The *Table* illustrates typical results. The center set of data is the unstable condition at 25 rpm on high-viscosity material; the stability was good through 0.007-inch clearance; was totally unusable at 0.015-inch clearance; yet there was essentially no further performance deterioration once the totally erratic condition was reached. In contrast the stability remained good with the low-viscosity material at the same speeds and with the high-viscosity material at high speeds throughout the entire test series. The test program yielded no broad guidelines on the exact wear point at which stability deteriorates. Processors must be aware that it *can* occur, probably as a step function. *Figure 5* is a typical recording of unstable conditions.

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[d] L C 732, United States Industrial Chemicals

[e] NPE 320, Northern Petrochemical Co.

The processor should also note that adverse instability problems may be associated with one design of screw, and yet not carry over to other designs, to metering designs, or to barrier screws. The "zone of instability" is, perhaps, an explanation of the tendency of some industries (for example, wire and cable) to find wear-associated stability problems, since these industries tend to oversize their extruders somewhat, and thus operate at low speeds. Other industries (such as the film industry) typically push extruder speed to the polymer melt-temperature limits, and thus may always operate outside of the "zone of instability" regardless of wear.

Melt temperature

At constant speed minimal differences in melt temperature were observed between the start of the test series to the high-wear condition. There would, of course, be an increase in temperature as the extruder was sped up to account for wear. This forces us to question the frequently heard theory that melt temperature increases with increasing leakage flow.

Energy utilization

At a constant speed, a definite increase in drive horsepower per pound was observed as the screw was artificially worn down. Obviously, as speed increases, horsepower per pound also increases. The total of both of these factors together can yield as much as 1/4 to 1/2 cent per pound added energy charge for every pound processed.

With the microprocessor test setup that we used, it was possible to note changes in the barrel heat input. These changes were minor, but there appears to be a shift in the location of the barrel heat input, reducing somewhat in the zone at the start of the worn area and increasing in the zone at the end of the worn area, thus giving evidence of energy losses.

Costs of screw wear

It is important to consider the economic consequences of screw wear. Three typical cases will be described. To keep the factors in their proper prospective the processor must constantly be aware that the dollar value of product processed by a typical screw in one 24-hour day approximately equals the price of that conventional screw. This may be startling, but it is true. Consider, for example, an output rate of 300 pounds per hour on a 3-1/2-inch extruder, with a 55-cents-per-pound selling price for a low-density commodity film, and 20 hours a day of productive operation. That equates to $3300 of salable product, or very close to the price of a typical mixing screw today.

Case 1. The line limitation is that either the extruder speed is the maximum available, or the melt temperature is limited by the extruder speed. Assume that wear before replacement is 15 percent, and the increase of output with a new screw is 15 percent (which may well be seriously understated as discussed above). Therefore, in 7 days the screw has generated added product equal to its cost. That product was produced with no added labor, little added capital charge, no added overhead or fringes, and less energy per pound than the old base. Basically the product was produced for resin, packaging, and sales costs. Marginal profit on that increment of product is probably in the range of 25 to 35 percent of the selling price. Replacement of that worn screw would pay for itself in marginal profit in three to four weeks.

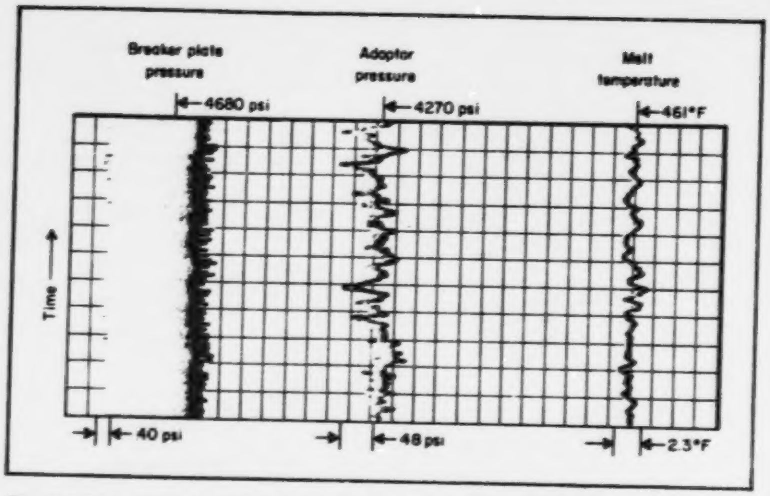

Figure 4. Typical recording of relatively stable extrusion represents only a 1-percent pressure fluctuation, unaffected by screw wear

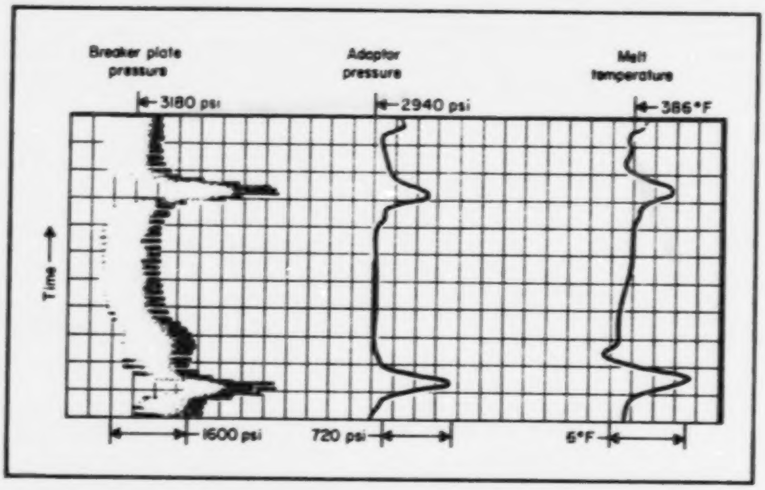

Figure 5. Unstable extrusion is illustrated by this recording. Exact wear point at which stability deteriorates was not estalished by test program.

Case 2. In this case the line limitation is downstream cooling. Assume again wear before replacement is 15 percent. Assume also that melt-temperature increases 6°F due to the increased speed needed to maintain the output. For a product that must be cooled from 380 to 80°F, 2 percent more Btus per pound of heat content must be extracted by the downstream cooling system. With a new screw the 6 F of heat extraction can be applied to an output increase of about 2 percent with the same heat-extraction limitation. Therefore, payout time is 50 days worth of product; payout time from marginal profit is 150 to 200 days.

In *cases 1* and *2* the side benefit of 1 to 2 percent of the screw price per week reduction in energy cost per pound of product has not been considered.

Case 3. Here the limitation is the quality of the output which has deteriorated into the "zone of instability." Wear before replacement can not be pinpointed in such cases since the zone of instability is a function of processing conditions. But because the product is jeopardized, there is no recourse except to replace the screw. Payout time is almost immediate; 1 day's worth of product, possibly up a week's of marginal profit. Perhaps even shorter, as you won't have to accept unsatisfactory product returns.

Summary

The screw wear tests that we have made show conclusively that the processor must keep aware of the potential of a serious profit drain caused by screw wear. Since the percentage rule often materially understates the adverse affects of wear, the processor must establish benchmark conditions and run those benchmark conditions periodically to keep track of the effects of wear in his particular processing conditions. Further, he should realize that even moderate wear may cause the on-set of serious instability problems. The return on investment in replacing a worn screw is attractive under moderate wear situations.

Note

A more detailed discussion of the topic, and a full set of data on these tests is published in the 1982 ANTEC preprint, XXVIII, PE441. A copy may be obtained from the author by writing to Davis-Standard Division, Crompton & Knowles Corporation, U.S. Rt. #1, Pawcatuck, CT 02891.

OPTIMIZING ENERGY UTILIZATION IN EXTRUSION PROCESSING

BY

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1981 ANTEC Extrusion Division Paper

INTRODUCTION:

As energy costs continue to rise, it becomes increasingly important to minimize energy consumption during plastic processing to the extent that this does not detract from productivity. For any continuous extrusion process the minimum energy theoretically required can be determined from thermodynamic characteristics of the feed stock and extrudate. However, no machine is ever 100% efficient, and there are many components of any commercial extruder that can consume extra energy. At the 1980 NATEC [1] we presented an approach to studying energy efficiency of both continuous extruders and reciprocating screw injection molding units. We also presented some of our preliminary findings showing that commercial extruders can be quite energy efficient.

Now, at the 1981 ANTEC we are presenting much more comprehensive results and interpretations. New insights, are provided, but we also recognize that the basic principles were established many years ago by such investigators as McKelvey and Bernhardt [2] and Maddock [3]. Unfortunately, in recent years several publications have implied that many processors may be using several times as much energy in drive HP for shear heating as is theoretically needed for melting [4,5]. In our experience this would appear to be very rare.

Our present study involved extrusion of two different polymers, both with three different screws, plus a third polymer with one of these screws. We have found that the overall energy efficiency at commercial extrusion rates typically ranges from about 45% to 75%. Of course, the energy efficiency depends very much on the screw design, extruder design, gearing, polymer feedstock, products to be made, and extrusion rate. Even though the screw design is a very important consideration, we would not expect very many screws used commercially to be operated below 40% overall energy efficiency. A poorly designed extruder screw can waste energy in various ways such as the following:

1) A poorly designed screw might result in drastically overheated melt unless operated at low RPM or with excessive barrel and screw cooling. Obviously, heat extracted through the barrel wall (or screw cooling) represents a loss in energy efficiency.

2) A poorly designed screw might give inadequate melting and/or melt mixing, which may limit the operation to inefficient conditions.

Ideally, we want a screw which delivers high output with adequate melt quality, melt mixing, and stability at reasonably low melt temperature without the need for significant screw or barrel cooling. If the screw design fulfills these requirements, then further improvements in screw design cannot dramatically increase energy efficiency.

ENERGY BALANCE

To determine the overall energy efficiency and highlight areas of potential energy savings the "energy balance" approach to polymer processing was examined. The theoretical energy requirement for melting and forming the product during extrusion can be expressed as follows:

$$P_T = \dot{m}\int_{T_1}^{T_2} C_p\,dT + \dot{m}\,v\,\Delta p$$

Where P_T = Total (net power to polymer)

$\dot{m}$ = Mass flow rate of polymer

T_1, T_2 = Screw inlet and discharge polymer temperature, respectively.

C_p = Specific heat capacity of polymer

v = Specific volume of the polymer melt

Δp = Screw discharge pressure

In Equation (1) the term "$\dot{m}\,v\,\Delta p$" is the power required for forming through the die (usually less than 5% of total); while the other term on the right side of the equation can be considered the power required for melt preparation. The $\int_{T_1}^{T_2} C_p\,dT$ is simply the area under the polymer specific heat/temperature curve between the entering and exit temperatures. The energy efficiency of the extruder is P_T (computed from Equation (1) divided by the total power input to the extruder, which we determined with a recording three-phase wattmeter connected to the AC power supply line entering the extruder.

The total power input equals total (net) power to the polymer plus losses. The biggest energy losses occur in the drive train and in heat loss and/or forced cooling through the extruder barrel wall. However, there are many other small losses, as noted in Figure 1. A complete energy balance determination was not possible, but a qualitative example of all elements of the energy balance appears in Table I.

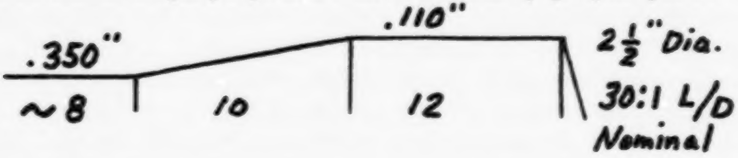
DATA COLLECTION PROCEDURE

For a 2-1/2" Diamater 30:1 heavy duty 75 HP extruder we monitored temperature and pressure fluctuations for the melt in the die adaptor very sensitively utilizing a Hewlitt Packard 8-channel oscillograph recorder. Five channels were devoted to monitoring time "off" and "on" for the water cooling and electrical heating of each barrel zone. Drive HP output for the DC motor was calculated from DC amps using the following formula:

$$\text{HP} = \frac{\dfrac{\text{Measured Actual RPM}}{\text{Maximum Rated RPM}} \times \begin{array}{c}\text{Max.}\\ \text{Arm.}\\ \text{Volts}\end{array} \times \begin{array}{c}\text{Meas.}\\ \text{DC}\\ \text{Amps}\end{array}}{746} \times 0.9$$

Most other data came directly from the extruder control panel, the AC recording wattmeter, and direct measurement of screw RPM and output.

The screw designs for the primary study included the same single stage "double wave" screw used in two of our previous ANTEC papers [6] [7] . The other high performance design was a "Max Melt" (controlled melting) screw. Design principles of the three screws are illustrated in Figure 2 . The conventional screw with the following profile was considered rather typical for non-vented extrusion of polystyrene and low density polyethylene.



The polymers extruded with this heavy duty 75 HP extruder were Union Carbide type DYNH (2 M.I.) polyethylene and Cosden type 825E Sheet Grade Impact polystyrene.

In studying performance with a lighter duty more heavily loaded 50 HP air cooled extruder we used the same "double wave" screw to extrude Phillips TR880 high density polyethylene.

OVERALL ENERGY EFFICIENCY RESULTS

Tables 2, 3, and 4 present the data compiled to determine overall energy efficiencies under various extrusion conditions. In examining the data in Table 2 for a low density polyethylene note that the overall energy efficiency is lowest at the lowest screw speeds even through the drive power economy (Lb/Hr/HP) is highest. At low screw speed a considerable portion of the total energy input was found to come from the barrel heaters; so the drive power economy gave no indication of overall power economy (Lb/Hr rate divided by total measured electrical power input). [The term "power economy" as used in Reference 2 is sometimes also referred to as "specific power".]

The overall power economy in Table 2 reached 7.4 Lb/Hr/Hp for the "double wave" screw operating "adiabatically" at both 99 and 170 RPM. With both the heating and cooling of the barrel turned off for an extended period (30-40 minutes) we called the extrusion process "adiabatic", although not strictly true. Note that barrel temperatures did not quite level out completely, as illustrated in Figure 3. However, for low density polyethylene these virtually "adiabatic" extrusion conditions gave highly uniform extrudate melt quality with the "double wave" screw, well-suited to critical applications.

The "Max-Melt" screw under somewhat modified extrusion conditions also gave highly uniform extrudate melt quality and reasonably equivalent overall energy efficiency for this polyethylene. The energy efficiency appeared slightly worse than the "double wave" at low discharge pressure and slightly superior at high discharge pressure. No adiabatic data was collected for the " Max Melt" screw.

By contrast the conventional screw gave lower energy efficiency and exceptionally poor melt quality for the low density polyethylene at the highest screw speed (175 RPM). Many pecple knowledgeable in extrusion would consider this a fairly typical conventional single stage screw design for 2 M.I. low density polyethylene. However, at high screw speeds the melt quality was strikingly inferior, as illustrated in melt temperature and pressure fluctuation graphs shown in Figure 4.

The data in Table III for the high impact polystyrene generally show lower overall power efficiency than for the polyethylene. Apparently, the lower theoretical HP requirement in combination with the higher barrel temperature requirement (for proper melt preparation) tend to reduce the energy efficiency. Higher barrel temperature leads to larger convective heat loss. However, again note that the overall energy efficiency is lowest at the lowest screw speeds even though the drive horsepower economy is highest. Unlike the polyethylene results there was not a major difference among the three screws in overall energy efficiency. Nevertheless, the conventional screw was judged inferior because it yielded a highly inferior melt quality at high screw speeds, as illustrated in Figure 4.

We recognize that other high performance screw designs are available to improve melt quality at high screw speeds, but we have no information on how such screws compare in overall energy efficiency.

The data in Table IV for the high density polyethylene extruded up to full load in an air cooled lighter duty extruder with the "double wave" screw illustrate exceptionally high overall energy efficiencies. The low barrel zone temperatures in combination with high theoretical HP requirement tend to give improved energy efficiency. Furthermore, the DC drive operated closer to full load, which tends to improve its efficiency.

DC DRIVE SPECIAL CONSIDERATIONS

To more fully explain lower overall energy efficiencies usually observed at low extruder screw speeds we contacted engineers at several DC drive vendors for detailed information on drive characteristics. In the 1977 IAS Annual of the IEEE [8] J. S. Ewing presented performance data for a 60 HP DC drive operating at full load and full 1750 RPM motor speed. The overall efficiency was 86.9% (about 1% rectifier loss and a little above 12% motor loss). The overall efficiency dropped slightly to about 83% at 50% load but all the way down to 70% at 20% load. Although not covered in Ewing's paper, we are advised that the penalty for operating at low motor speeds is rather severe. The total motor losses and rectifier losses won't change much in absolute magnitude as a function of screw speed; so percentagewise they become more important at low screw speed. Of even greater financial significance, the displacement power factor is almost entirely a funtion of operating speed, shifting from 84% at full speed to 60% at 75% speed to only 26% at 30% speed [9] .

It is often wise to buy a more powerful drive than necessary for the planned extrusion application because then the extruder is adaptable to other feed materials and increased production capacity. However, to minimize energy costs the extruder should be geared to operate close to maximum DC motor speed with provision to change the speed range if needed in the future. Operating at 50% load costs very little extra but operating at 50% speed can add significantly to energy costs.

The actual cost penalty for inefficient energy utilization may not be very severe for small scale operations located in a low cost power area. Note in Figure 5 that wasting 10 HP at 3¢ per K WH would only add about 20¢ per hour to costs (neglecting power factor penalties). On the other hand, operating many small extruders or a few large extruders inefficiently can add many thousands of dollars annually to operating cost, especially where high electrical utility rates apply. For example, six 4-1/2" diameter heavily loaded extruders operating simultaneously in a production plant might represent a combined input power load of 1000 K W. If the usage averaged 6000 hours per year at 6¢ per K WH average power cost, then the electric bill would total $360,000 annually. Obviously, a 10% reduction in energy use could save $36,000 annually, which is very much worthwhile.

In one plant about this size in the midwest we know that a reduction in power factor from 96.2% to 80% would add almost 12% to the electric bill; so there can be a major cost disadvantage when operating DC extruder drive motors at low speeds. By selecting the proper extruder screw speed range DC drives can be operated with high efficiency for most applications.

OVERALL INTERPRETATION OF RESULTS

Overall efficiencies reported in Tables II, III, & IV were rather sensitive to the calculated value of theoretical HP requirement, which always assumed that the exit melt temperature was the ideal melt temperature. Obviously this was not always the case. Often improved melt mixing affects product quality more than the average temperature at the screw tip, making it possible to save energy by lowering melt melt temperature. However, most melt temperatures recorded in these tables were in the typical range of commercial applications; so the overall efficiencies calculated were qualitatively very typical at the highest screw speeds. At lower screw speeds the overall energy efficiencies would have been higher if the extruder had been geared for higher motor speeds with motors sized to operate at about 50% or more of rated amperage load.

As stated previously, screw design is extremely important to achieve high melt quality in combination with high production rates and reasonably low melt temperature. When extrusion conditions can be established which achieve this result with very little or no barrel cooling or screw cooling, then the extruder can be operated at close to maximum efficiency. It should be recognized that all of the screws evaluated were adequately designed to avoid the need for excessive cooling or seriously overheating the melt. Less adequate screw designs could be much less energy efficient. However, we would consider it rare for modern extruders to be operated commercially at overall energy efficiencies below 30 to 40%, and many could be operating at 60-70% overall energy efficiency, some even higher.

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ENERGY LOSSES

FIGURE 1

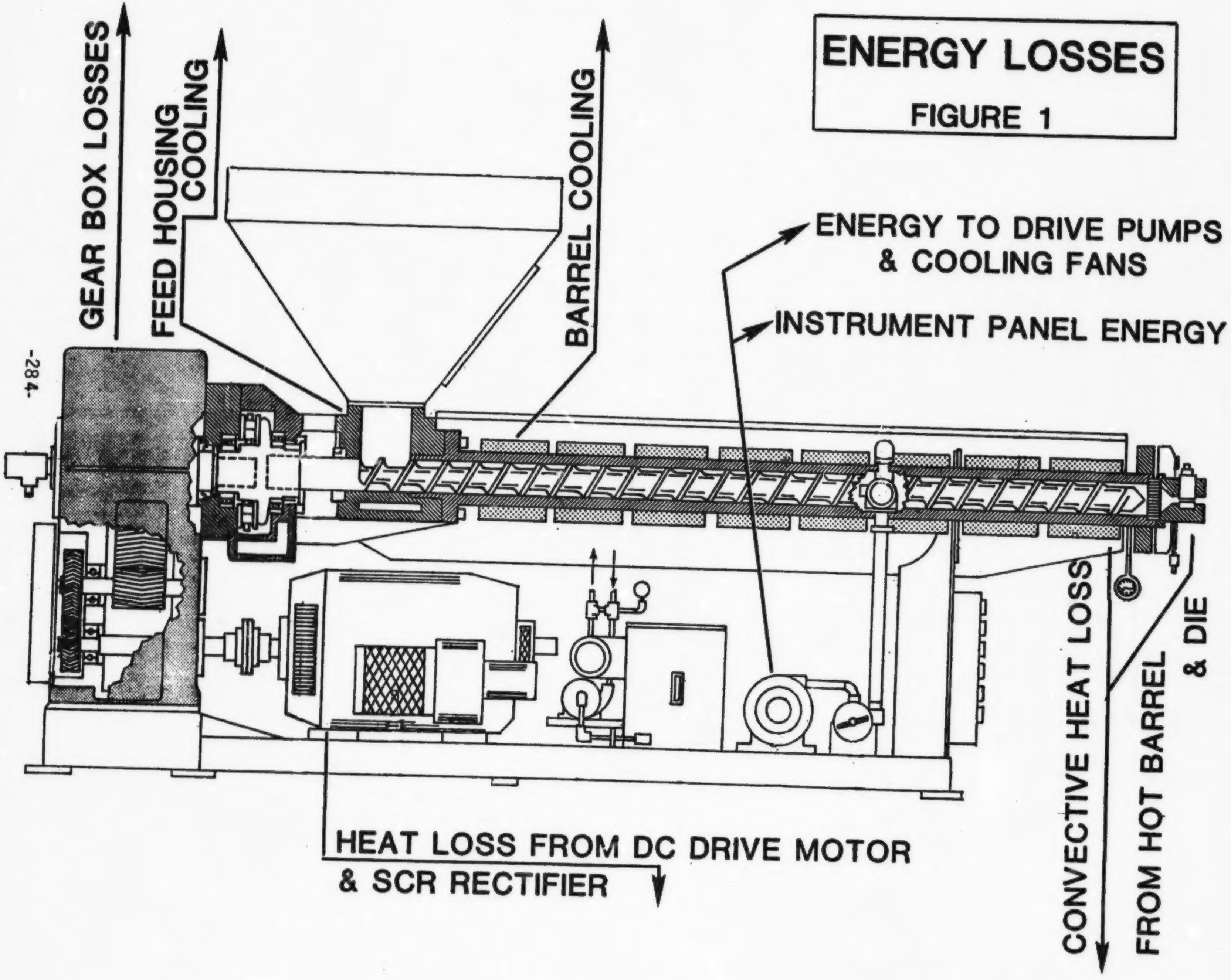
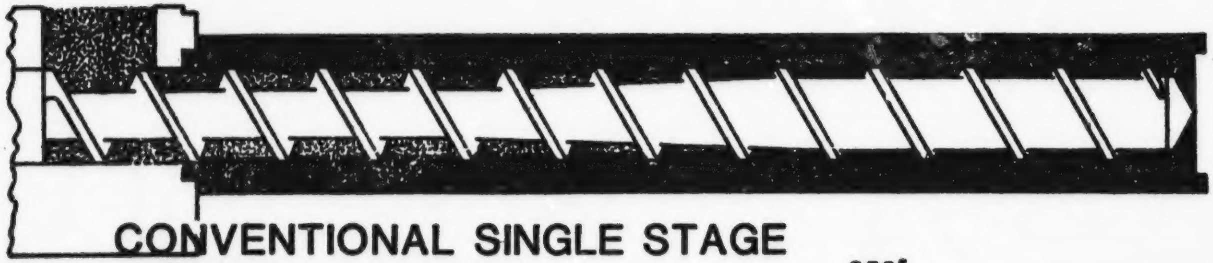
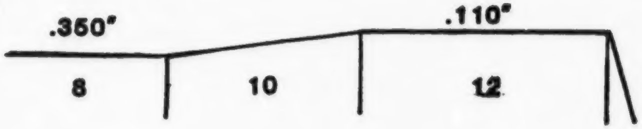
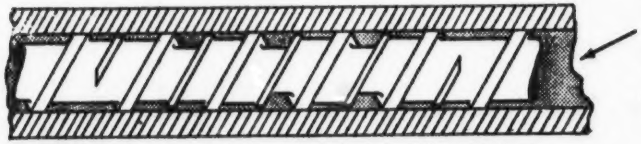

GEAR BOX LOSSES
FEED HOUSING COOLING
BARREL COOLING
ENERGY TO DRIVE PUMPS & COOLING FANS
INSTRUMENT PANEL ENERGY
HEAT LOSS FROM DC DRIVE MOTOR & SCR RECTIFIER
CONVECTIVE HEAT LOSS
FROM HOT BARREL & DIE

FIGURE 2 – DESIGN PRINCIPLES OF TEST SCREWS



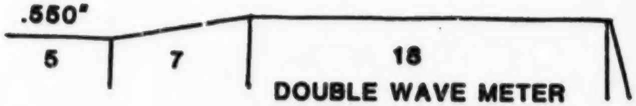
CONVENTIONAL SINGLE STAGE SCREW

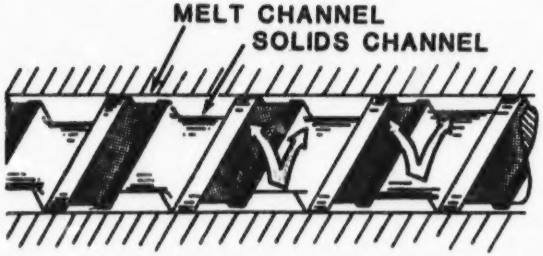

.350"
.110"
8
10
12



TYPICAL DOUBLE WAVE METERING SECTION

THE DOUBLE WAVE DESIGN FEATURES AN UNDERCUT BARRIER FLIGHT BETWEEN ALTERNATING WAVES IN TWIN CHANNELS.


.550"
5
7
18
DOUBLE WAVE METER


MELT CHANNEL
SOLIDS CHANNEL

"MAX MELT" DESIGN

USED WHERE PROLONGED CONTROL OF MELTING IS OF MAJOR IMPORTANCE.

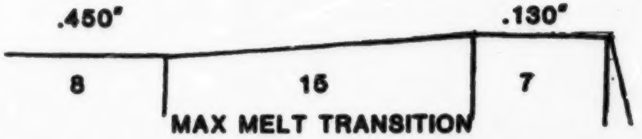

.450"
.130"
8
15
7
MAX MELT TRANSITION

FIGURE 3
APPROACH TO EQUILIBRIUM IN "ADIABATIC" EXTRUSION

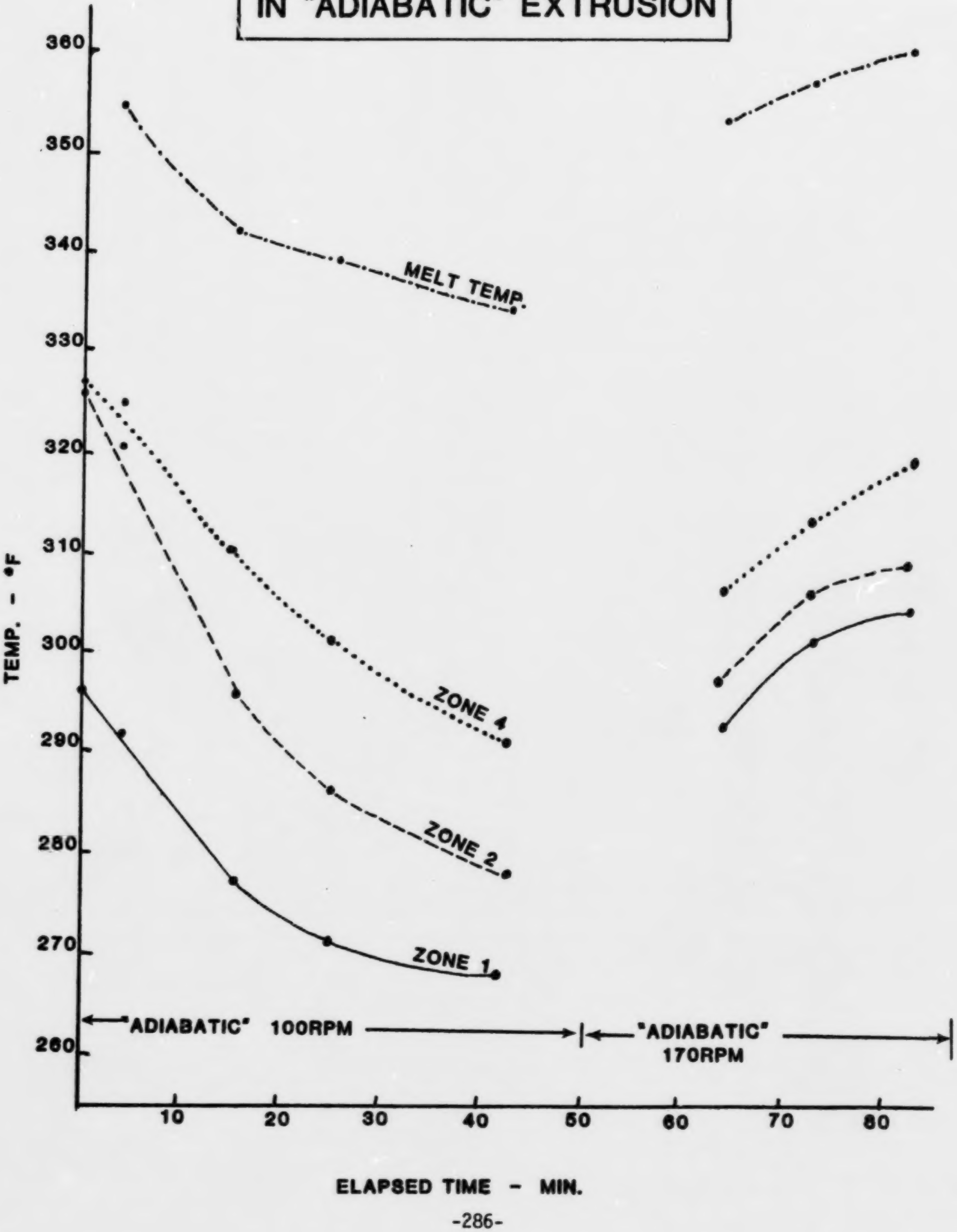


FIGURE 4 - MELT TEMPERATURE AND PRESSURE FLUCTUATIONS AT HIGH SCREW SPEEDS (170-176 RPM)

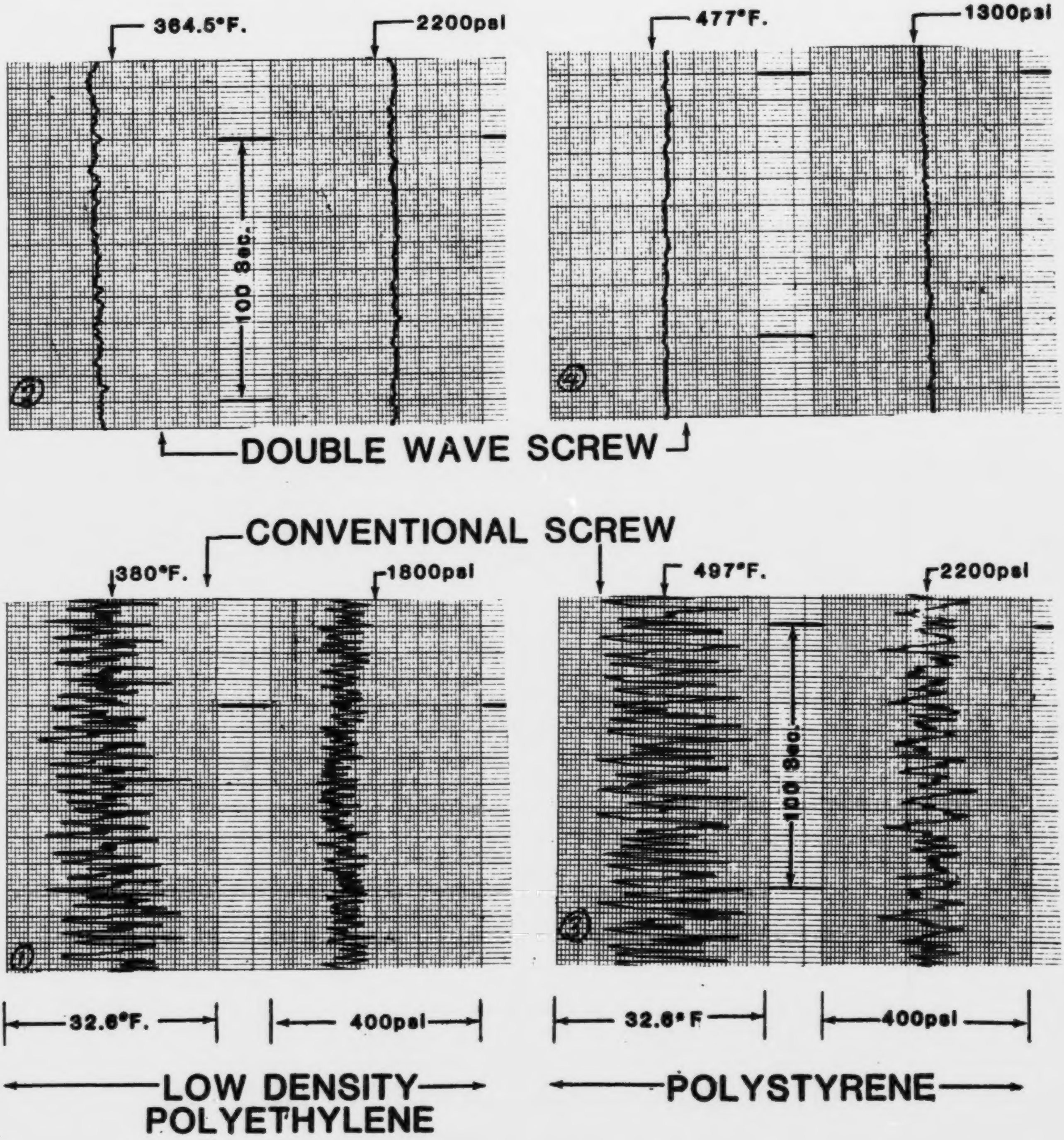


FIGURE 5
ELECTRICAL ENERGY COST

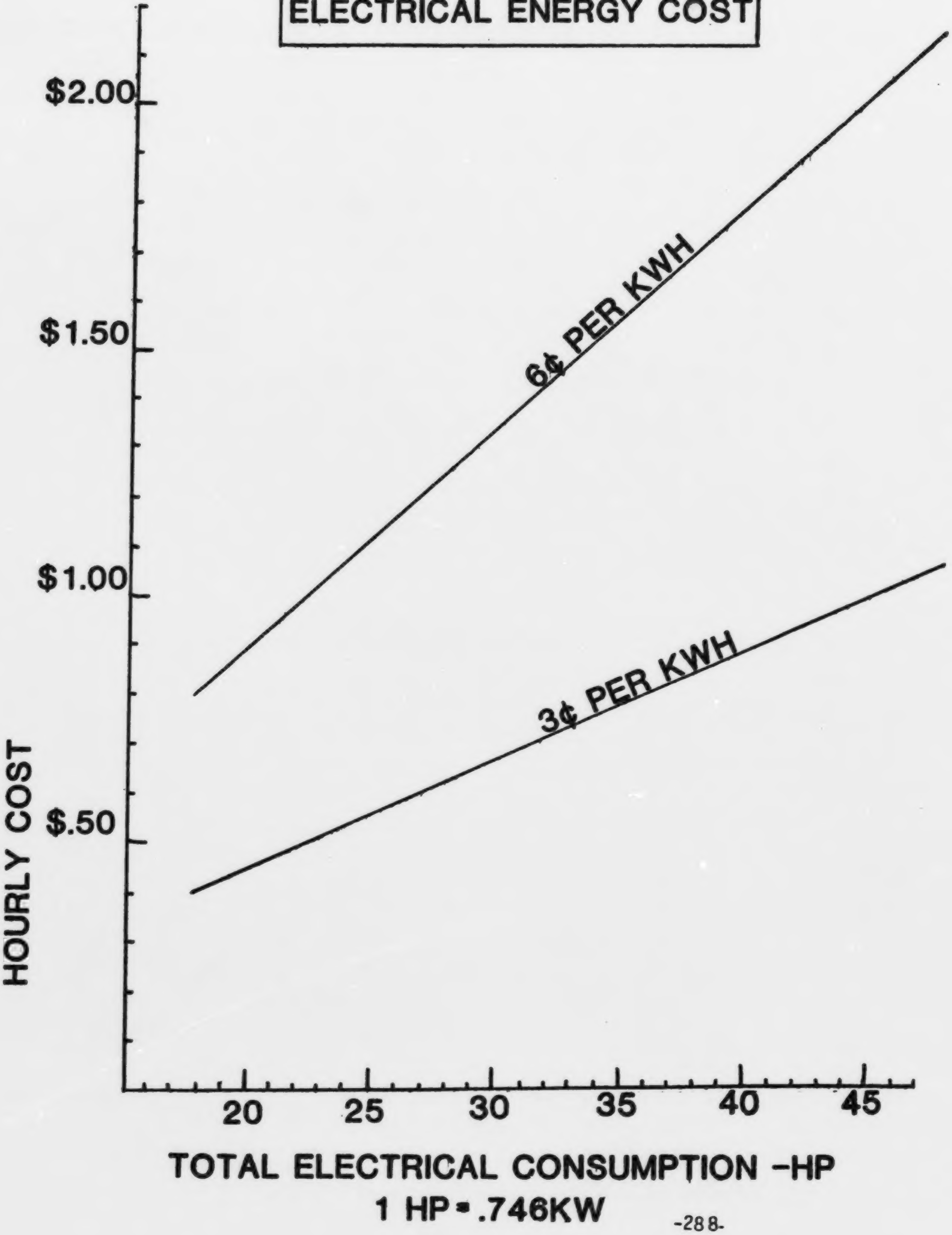


TABLE I - QUALITATIVE EXAMPLE OF ALL ELEMENTS OF AN EXTRUDER ENERGY BALANCE

AC ENERGY INPUT DISTRIBUTION

Drive	76.2%
Drive Motor Cooling Fan	.8%
Rectifier Cooling Fan	.2%
Barrel Heaters	18.6%
Die & Adaptor Heaters	2 %
Instrument Panel	.2%
Cooling Water Recirculating Pump Or Blowers For Air Coded Barrel	2 %
Vacuum Pump (Vented Extruders)	0 %
Screw Temp. Control Unit	0 %

ENERGY LOSS DISTRIBUTION

Barrel Forced Cooling Heat Loss	8 %
Barrel & Die Heating Added Convection Losses	8 %
Water Cooled Feed Hopper Loss	1 %
Rectifier Loss	1 %
DC Drive Motor Loss	14 %
Gear Box Loss	4 %
Water Recirculation Pump Loss	2 %
Cooling Fans For Drive Motor & Rectifier	1 %
Instrument Panel Loss	.2%
Vacuum Pump Loss	0 %
Screw Cooling Loss	0 %
Overheating The Polymer	0 %

OVERALL ENERGY EFFICIENCY

100% Energy Input - 39.2% Loss = 60.8% Overall Energy Efficiency

NOTE: This example does not represent an actual case, but illustrates qualitatively a typical distribution of energy inputs and losses resulting in 60.8% overall energy efficiency, using no screw cooling or venting.

TABLE II - ENERGY EFFICIENCY FOR EXTRUDING LOW DENSITY POLYETHYLENE

(2 Melt Index Union Carbide Type DYNH In 75 HP Heavy Duty Extruder)

Screw RPM	Output Lb./Hr.	Exit Melt		Nominal Barrel Temp. °F.		DC Drive HP	Drive Power Economy Lb/Hr/HP.	Measured Total Power HP Equiv.	Overall Power Economy Lb/Hr/HP.	Theoretical Required HP	% Overall Efficiency
		Temp. °F.	Pressure PSI	Zone 1	Zones 2-5						
DOUBLE WAVE SCREW											
52	97	349	1020	300	325	6.5	15.0	18.4	5.3	8.5	46.3
99	189	355	1320	300	325	15.8	12.0	28.5	6.6	17.1	60.0
99	189	334	1420	268	278-291	17.9	10.5	25.6	7.4	16.0	62.5
				Adiabatic							
100	189	357	1300	275	300	15.3	12.4	26.5	7.1	17.1	64.5
100	142	374	3500	275	300	14.9	9.5	26.0	5.5	13.9	53.3
				Valved to higher pressure							
175	242	392	4400	275	300	30.5	7.9	44.1	5.5	25.1	56.9
170	326	360	1610	304	289-317	34.2	9.5	43.7	7.5	29.8	68.2
				Adiabatic							
170	326	368	1550	300	325	34.1	9.9	45.2	7.2	30.5	67.5
CONVENTIONAL SCREW											
50	74	341	900	300	325	5.2	14.2	17.1	4.3	6.3	36.6
100	153	362	1100	300	325	15.2	10.1	28.6	5.3	13.7	47.9
100	152	370	1125	280	302-341	15.5	9.8	23.9	6.4	13.8	57.7
				Adiabatic							
100	146	368	2500	300	325	15.7	9.3	26.9	5.4	13.6	50.6
				Valved to higher pressure							
175	253	387	2900	300	325	34.2	7.4	46.1	5.5	24.5	53.1
175	265	378	1350	300	325	33.5	7.9	45.6	5.8	24.9	54.6
"MAX MELT" SCREW											
75	131	368	2150	325	350	13.1	10.0	25.1	5.2	13.0	51.8
125	212	380	2440	325	350	26.5	8.0	36.9	5.7	21.6	58.5
174	300	395	2680	325	350	42.2	7.1	52.0	5.8	31.9	61.3
				Valved to higher pressure							
174	325	385	1360	325	350	42.9	7.6	53.6	6.1	33.2	61.9

TABLE III - ENERGY EFFICIENCY FOR EXTRUDING POLYSTYRENE
(Cosden High Impact PS Type 825 E In 75 HP Heavy Duty Extruder)

Screw RPM	Output Lb./Hr.	Exit Melt		Nominal Barrel Temp. °F.		DC Drive HP	Drive Power Economy Lb/Hr/HP.	Measured Total Power HP Equiv.	Overall Power Economy Lb/Hr/HP.	Theoretical Required HP	% Overall Efficiency
		Temp. °F.	Pressure PSI	Zone 1	Zones 2-3						
"DOUBLE WAVE" SCREW											
50	124	454	670	400	450	7.7	16.1	23.1	5.4	8.1	35.1
100	217	474	850	400	450	16.7	13.0	30.7	7.1	15.1	49.2
100	220	447	1020	374	365-397	19.0	11.6	26.8	8.2	14.1	53.0
				Adiabatic							
100	180	483	1975	400	450	14.5	12.4	28.6	6.3	13.1	45.8
				Valved to higher pressure							
176	284	493	2610	325	400	29.9	9.5	44.2	6.4	21.4	48.4
176	325	465	1470	325	400	32.2	10.1	44.5	7.3	22.2	49.9
176	305	481	900	400	450	27.3	11.2	45.2	6.7	21.7	48.0
176	320	468	1075	415	360 - 407	31.4	10.2	40.2	8.0	22.0	54.7
				Adiabatic Unstable							
CONVENTIONAL SCREW											
50	100	460	800	400	450	8.5	11.7	22.6	4.4	6.7	29.8
100	195	479	800	400	450	18.0	10.8	31.8	6.1	14.0	44.0
175	310	489	900	400	450	31.5	9.8	44.0	7.0	22.1	51.6
175	305	496	1940	400	450	32.8	9.3	45.2	6.7	23.5	52.0
				Valved to higher pressure							
"MAX MELT" SCREW											
75	149	450	1360	425	450	11.4	13.1	25.1	5.9	11.0	43.9
124	236	470	1470	425	450	24.9	9.5	35.2	6.7	18.0	51.1
174	321	482	870	425	450	36.9	8.7	46.9	6.8	24.8	52.9

TABLE IV - ENERGY EFFICIENCY FOR EXTRUDING HIGH DENSITY POLYETHYLENE
(Phillips HDPE Type TR880 In Air Cooled 50HP Lighter Duty Extruder)

Screw RPM	Output Lb./Hr.	Exit Melt		Nominal Barrel Temp. °F.		DC Drive HP	Drive Power Economy Lb/Hr/HP.	Measured Total Power HP Equiv.	Overall Power Economy Lb/Hr/HP.	Theoretical Required HP	% Overall Efficiency
		Temp. °F.	Pressure PSI	Zone 1	Zones 2-5						
DOUBLE WAVE SCREW											
100	192	395	700	300	330 Ave.	21.2	9.1	29.1	6.6	22.1	75.7
150	303	368	1000	300	"	36.1	8.4	45.5	6.7	33.1	72.7
200	370	388	1050	300	"	51.7	7.2	59.4	6.2	42.3	71.1

APPENDIX I.1

MICROPROCESSOR CONTROLS

Note- The following literature is provided to assist the processors but its inclusion here does not constitute any endorsement.

1. Emphasis on Electroncis + Energy Saving
   F. Lenk and J. Pineault
   Reproduced from Canadian Plastics
   December 1981

2. Scoremaker Microprocessor Controller
   Solid Controls Inc.,
   Minneapolis, Minnesota

3. Maco IV, V, and VI Microprocess Controllers
   Barber-Colman of Canada Ltd.,
   Weston, Ontario

4. Reducing I.M.M. Power Consumption Through Controls
   N.Atkins and J. Bohenko
   Farrel Machinery Group, Emhart Corp.,
   Ansonia, Conn.

Plastics technology developments *by Frank Lenk + Jacques Pineault*

Emphasis on electronics + energy savings

Microprocessor control and energy-efficiency are key to advances in plastics machinery. Canadian suppliers are ready to serve the market when the revolution spreads here.

Canadian molding machinery producers and suppliers are increasingly adopting a high profile worldwide with new twists and refinements to their lines. Economic conditions being what they are, these equipment firms are not having an easy time installing the new technology in the domestic plastics processing industry. That this situation will eventually change is heralded by healthy sales of the technologies to foreign customers. In fact, some machinery firms are experiencing greater sales outside of the country than within to parties hungry for the latest developments.

Conferences held for the plastics industry in the last year presented glimpses of the changing faces of processing machinery. Canadian Plastics contacted machinery suppliers to discern the trends occuring in machinery innovation. The following report is not intended to be a complete survey of the suppliers operating in Canada, but rather is a summary of the directions in which machinery is moving. Some examples are provided to illustrate these trends.

There is little doubt that high interest rates have had the effect of a bucket of cold water on the molding equipment market. While sales of used and reconditioned machines continue to show moderate activity, sales of high-capital items are way off their form. Paradoxically, the major innovations in machine design are nothing if not cost-saving — yet few can at present afford to take advantage of them. Even so, such demand as remains for new equipment has been focussed on rather tradition-bound lines. The next two or three years — whatever they may bring in the way of an economic recovery — will surely see greater willingness on the part of domestic processors to "get their feet wet" in those new techniques that have already swept the European and U.S. markets.

An industry spokesman points out that the average age of machinery in North America is now 12 years, versus 4 years in Japan. He suggests that Canadians could keep up to date by buying more sophisticated equipment and scrapping out-of-date machines. The problem here is that "there are too many little guys" who will pick up outdated machinery on the cheap — "and that's not helping the industry."

It must be noted that as far as molding-equipment technology is concerned, Canada has never had to take a back seat. Not as long as it harbored such innovative specialist manufacturers as Husky Injection Molding Systems (Bolton, Ont). Always at the forefront of design, Husky estimates that only about 5-7% of its present output sells within Canada, while 40% goes to the U.S., 35% to Europe, and 10% to Japan. Dave Cook, vice-president in charge of marketing at Husky, cites the company's "efficiency, high quality and technological specialization" as the chief reasons for its international success.

Other domestic machine manufacturers also offer world-class state-of-the-art products. One example is Ludwig Engel Canada (Guelph, Ont), which, according to sales manager Kurt Fenske, has been building sophisticated microprocessor-controlled injection-molding machines "for some time", even though these have so far been selling only on the U.S. side of the border. Corma (Concord, Ont) has for 10 years been a world leader in corrugated-pipe systems, offering a technology built entirely "from scratch" in Canada.

Husky has pointed out, however, that the market is shrinking — total U.S. sales have declined from 5,000 machines annually in the mid-70s, to only 3,500 at present.

The two dominant themes in equipment design at this time differ fundamentally in their origins as well as in their impact on the domestic molding scene. The move to increasing energy efficiency is being brought on by economic demands endemic to our times, but felt more lightly in Canada than almost anywhere else in the world. Hence we are now seeing an influx of energy-efficient equipment designed to cope with overseas energy costs that to us may yet seem nightmarishly high.

The other major change, however, follows the reverse pattern: it is a technologically-motivated change that is having an impact on every part of the worldwide plastics marketplace.

Energy efficiency is achieved in the Kawaguchi KS-S injection flow- control valve in combination with a pressure relief valve to limit pump pressure to the particular load required during different stages of the machine cycle.

This shift is the sudden emergence of integrated electronics and particularly microprocessors to complete dominance as the cheapest, simplest and most practical type of control system for all forms of processing equipment. All over the world the move to these new controls is virtually a *fait accompli.*

Yet Canada continues to lag behind. Battenfeld reports that though its equipment is up to date with the demanding European state-of-the-art, in Canada more inquiries are made on the basis of a "standard" line of machines featuring solid-state electronics as opposed to self-diagnostic microprocessor controls.

Canada to catch up

It appears that it will be about 2-3 years before microprocessor controls will begin to see widespread acceptance in Canada. At a cost presently in the $8,000-$15,000 bracket, not every molder can benefit from these sophisticated systems. However, for those producing fairly tight-spec items, and/or those wishing to remain competitive in the export market, the "edge" they offer will surely seem more desirable. Judging by their progress up to now, these electronics should only take a few years to come down to a price that will allow even the smaller operator to experience the simplicity and ease of operation they offer.

Two reasons are cited by the suppliers to explain Canada's reluctance to adopt the new systems. First and foremost is a general distrust of this new technology, a fear that the leap will prove a) difficult, and b) unjustified. Equipment suppliers point out in rebuttal that the integrated electronics (not necessarily of full-blown computer capability) have already proven themselves *easier* to use than older types, and offering demonstrable economic payoffs in many applications. In addition to this general lack of awareness is a specific lack of trained operating and maintenance personnel. The system suppliers have an answer for this problem as well, as all offer either a training program of their own or tie in with the excellent programs offered by the manufacturers themselves.

Ludwig Engel Canada, in Guelph, Ont, reports that it has been building and selling some microprocessor-controlled equipment already, but only to the U.S. (With close ties to European technology, the company maintains world-class expertise.) Engel reports that operator training for microprocessor systems is now becoming widely available in Canada. Engel actually handles all training itself, for both machine and control. This is in contrast to the situation in the U.S., where the prevalent approach has had machine and control suppliers working more independently, apparently resulting in possible gaps both in training and technical back-up for the system as a whole.

Moving with large models

En-Plas in Scarborough, Ont reports reasonable demand for microprocessor controls for use in conjunction with larger molding machines in the over-500-ton clamp range. It has sold a number of sophisticated Barber-Coleman MACO-IV control systems in conjunction with heavy Farrel machines. However, at $15-20,000, these MACO-IV controls are justifiable only on relatively expensive installations where they become, in effect, a fairly minor option. Nissei *Conjet* process controls, though suited to smaller molding machines, sport a $10-15,000 price tag, making them justifiable primarily on high-precision applications.

Reports on the state of the machinery market are mixed, ranging from cautious optimism to grim determination. The consensus is that sales have not

Rubbermaid: a microprocessor success story

Rubbermaid (Canada), in Mississauga, Ont, is one molding operation that has been ready to receive the electronic revolution within its doors. Bill Wood, the company's engineer, reports that it has been about 4 years since Rubbermaid last operated a relay-controlled molding machine. Having developed a taste for Barber-Coleman control systems, Rubbermaid now owns 4 of the sophisticated MACO-IV microprocessor control systems, and over 10 of the simpler MACO-III integrated controls on its Farrel machines. As Wood describes it, the company has never looked back.

In use at Rubbermaid since 1975, the MACO-III is termed a "microprocessor sequential control". It does not control temperature or linear position, but is rather a "softwired" version of the standard "hardwired" relay control system. Elimination of all the complex physical wiring and mechanical contacts has two obvious benefits: greatly improved reliability, with a service life about equal to that of the molding machine itself; and vastly simplified operation. The MACO-III is designed to simulate relay circuitry, so that it is programmed directly from a standard ladder diagram of the desired logic. Internal problems are usually limited to the first day or so of operation, while with relays the real trouble doesn't begin until after a few years of operation, when things start to give out. Of course, the electronic system is essentially devoid of moving parts. The MACO-III provides for the equivalent of 256 input-output combinations.

The MACO-IV system goes several steps beyond the MACO-III. It uses a CRT console to provide complete control over the unit, as well as to offer a wide range of diagnostic read-outs in the event of any stoppage. It also incorporates the so-called Insta-Set feature, which permits all start-up parameters — including temperatures, linear position, air blow-off settings, hydraulic pressures, etc. — to be recorded on a small magnetic card, which can be stored and later used to re-set the machine for the same operation, even years later!

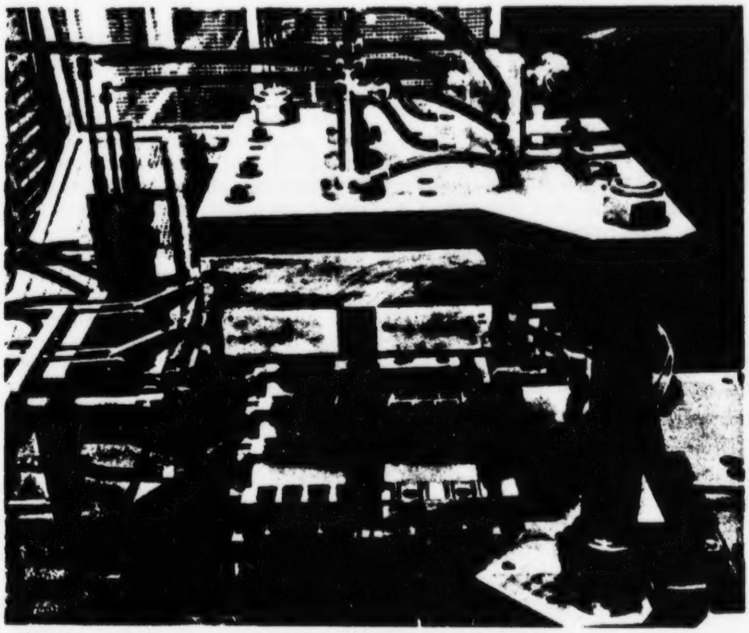
The MACO-IV also offers full process-control capability, although this feature is in fact not used by Rubbermaid, which finds that its own work is not really demanding enough to require it. However, with this feature working, a pressure-transducer installed in each mold would be used by the machine to self-control every cycle. Though the MACO-IV already provides full closed-loop hydraulic control, process control would provide still greater accuracy and freedom from fluctuation. Applications would include control over resin "packing" within the mold cavity, yielding highly accurate tolerances on the finished part.

Rubbermaid had little or no difficulty moving into electronic controls. In 1975 it had Barber-Coleman come in to do a 4-day training program relating to the MACO-III. In 1979 it repeated the process for the MACO-IV. These courses are offered by Barber-Coleman at a nominal charge.

If Rubbermaid's experience with integrated electronics has been entirely favorable, it should in all fairness be pointed out that the nature of the company's molding operation was entirely favorable to the incorporation of these systems. Producing a variety of large household items (such as laundry baskets, refuse containers, and the new "Fun-functionals" modular boxes, the company uses presses in the over-500-ton league. As the equipment suppliers point out, price tags in this size range — running around $0.75 million — make a $10-20,000 control system seem a relatively minor option.

The cost situation is actually even more favorable, according to Rubbermaid. Elimination of all other control systems from each MACO-equipped press saves an additional $5,000 or so per installation. Systems replaced by the MACO include both temperature and linear-position controls, with only the standard "J-type" thermocouple sensors left in place. Since Rubbermaid has all of its machines built to its own spec, use of the electronic controls also makes incorporation of extra options simpler and cheaper.

What has the actual payoff been for Rubbermaid? This seems a tough question to answer in specific terms, particularly since Rubbermaid itself admits that its own record-keeping is ill-adapted to this sort of determination. However, the company is in no doubt that the change has been more than worthwhile. It now runs all of its machines essentially without any supervision, with the nominal "operators" free to wander and take on other tasks in addition to the minimal overseeing duties on the molding press. Electrically-related downtime has certainly been cut drastically. But probably the biggest payoff has also been the simplest: just plain *ease* of operation.



'Wet-One' containers produced on package machinery equipment

been up to par. Opinions vary, however, as to just when and how much they have fallen off.

In general, the machinery business has become much more competitive over the past year or so — probably to the benefit of the few domestic manufacturers, who report fair-to-good sales and increasing displacement of imports. Importers report declining sales started within the last year. Most agree that business has held up best on the two extremes of the market — specialized or custom-built equipment, as well as the cheapest, rebuilt machines. High interest rates seem to be the chief reason for the split. Sales of lower-capital, higher return-on-investment items such as siloes and handling systems have apparently held up well.

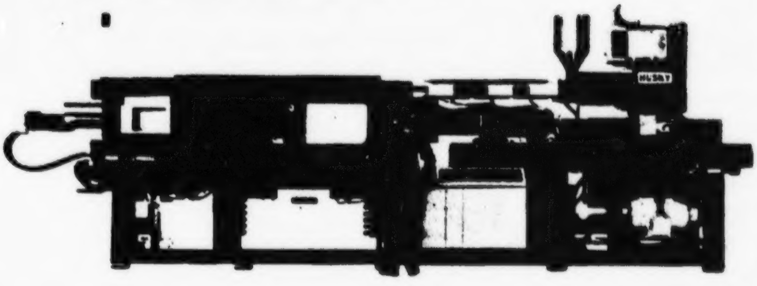
With some segments of the equipment market thought to be down by up to 30%, suppliers have been pressed to make the most of their respective strengths. The result has apparently been a buyers' market, with all the suppliers eager to please those molders with money to spend.

More efficient injection

Major changes are reported in two complete lines of injection-molding machines, highlighting perfectly the approach being taken by manufacturers overseas to combat the escalating cost of energy.

The Kawaguchi line of injection-molding machines has recently been entirely revamped, with emphasis on greater energy efficiency — a paramount concern in Japan where the line originates. Replacing the former KS-B line, the new KS-S machines incorporate a variety of energy-saving features. Like the former Kawaguchi machines, they use toggle clamping. The redesigned hydraulics use a flow-control valve to limit pressures at every moment during the cycle to the minimum required, rather than running at full pressure throughout — which necessitates extra cooling to take care of the waste heat. The machines also have a more efficient 3-stage digital electronic speed control, as well as a fully shielded screw barrel to reduce heat loss.

Speed improvements in injection molding are exemplified by Husky's new X series. This 330-ton unit provides up to 22 shot/min. using less than two gal of oil per shot.



Energy-saving changes have also swept over the Nissei line. The new machines use variable-displacement pumps and other changes in the hydraulic circuit to cut power consumption, reportedly by 30-70% compared to previous units. About 80% of Nissei's Japanese production has already gone over to the new configuration, while En-Plas reports that the first of the new machines is due to arrive in Canada shortly.

Spurred by the promise of good market potential — both in established fields such as construction profiles as well as in new areas such as electronics-related items — extrusion seems as a whole to be moving toward greater sophistication of design, particularly of screw design. Flag Machinery's Vive Waller suggests that PVC processors may find it worthwhile to move up to twin-screw machines. Though more costly initially, purchase of twin-screw extruders would allow a savings of as much as 8-10¢/lb by bringing the compounding step in house. Flag is also offering a free feasibility-estimating service for processors wishing to save energy by recycling their cooling-tower water.

Corma's new corrugators

Canada's resident expert in corrugated-pipe extrusion, Corma of Concord, Ont., has introduced what it terms "a new generation of small-diameter corrugators", consisting of 5 new models. All feature higher output rates than previous models, as well as the optional AMS — "automatic moldblock switching".

The AMS system permits size changes to be performed in just "a few seconds". It also permits incorporation of "cuffs" (integral couplings) used in applications such as swimming-pool hose at pre-programmed intervals.

Corma has also introduced what it terms two revolutionary corrugated plastic pipe systems. The first uses a profile extruder over an endless patented spiral to produce large-diameter spirally wound pipe (15 in. to 60 in. ID). Markets are sewer, slurry and culvert use. The second continuously extrudes large-diameter corrugated pipe (15 in. to 36 in. ID) and can use either blow molding or vacuum forming. It features a forming tool going over the outside to put in the corrugation. The second machine has a higher output speed but doesn't produce pipe as large as the first. Both machines can make dual-wall pipe.

Statements made by both Hubert Misera, manager at Package Machinery Co. (Canada) in Brampton, Ont., and Karl Fuhlrott, vice-president and general manager at Bekum Plastics Machinery in Toronto, showed considerable agreement as to the future of blow molding. "Evolution", said Fuhlrott, "continues at a steady pace, with the emphasis on increasing speed and improving efficiency." Misera reports typical speeds of 1,800 bottles per hour on the Fischer high-speed machines. Solid-state controls are now standard equipment on its double-station Fischer line, while the single-station line has relay controls as standard, with solid-state as an option.

First stretch-blower

Recently, a Nissei stretch-blow machine was sold to the Parke-Davis division of Warner-Lambert in Toronto. Operating since this April, the machine is the first of its kind in Canada (and likely North America as a whole) to be used for molding non-beverage bottles of PET (polyethylene terephthalate). These bottles, now on drugstore shelves, are in four sizes and replace the glass bottles formerly used to package Benylin cough syrup.

A rather promising market may soon be opening up in Canada according to Eric Hagan & Co., in Mississauga, Ont. — relating to the burgeoning market for the encapsulating of integrated-circuit chips. Stokes Division of Pennwalt is apparently the world's largest supplier of the transfer-molding presses used in this application. The largest demand for encapsulating has so far been in the Far East, but a domestic market may be about to develop, with the impending production of bubble memory chips by Mitel in Ottawa.

Brampton Engineering, in Brampton, Ont, reports some success with a revival of the downward-blow film extrusion concept. Originally intended for use with HDPE, the system is now also being applied to various resins and coextrusions. Rotation of the winder rather than die results in a much more even roll. Though the line must be installed either with the extruder on a tower or the line itself dropping into a pit, the pay-off comes in applications such as lamination, which can benefit from the smoother feed of film from a flawless roll. Gravity assist on the film take-off also seems to result in increased throughput. Several of these lines have reportedly been installed in Canada.

From Nelmor, of North Uxbridge, Mass., comes the Regenolux. This unit ingests the scrap by means of a cleated conveyor, chops it, then by means of a heating and rapid water-quench "pops" the material into a granular form. These granules should be easier for the extruder to re-use than the usual light, hard-to-convey flakes. The Regenolux is also capable of washing the scrap, apparently allowing such material as used garbage bags to be recycled. The first Canadian buyer of the Regenolux is a processor in the Montreal area.

Makron, the Canadian distributor for the Cannon line of RIM-urethane equipment, mentions a new system is now being carried — the Rimmodule. It is said to have the advantages of a custom-tailored system with the compactness and efficiency of a package unit. A water-curtain environmental system and double doors are included for operator safety. Makron has recently installed a more standard Cannon RIM unit at Sheller-Globe in Brampton, Ont. for its second RIM-urethane steering-wheel line.

The above discussion illustrates the kind of activity taking place in the equipment field. Dominant themes of microprocessor control and energy efficiency represent important developments for those entering processing or upgrading their systems. The new twists are more than novelties — they are geared to the processor's bottom line. An investment in the latest technology is a step to increase the competitiveness and thus profitability of the processor's operation. ♣

SCOREMAKER™ controlling the key variables

The standard injection molding machine with its attendant relief valves, pilot heads and limit switches is in a constant state of change. How great the changes, and how they affect the finished product, depend on the four biggest variables in the molding process: the machine itself (including the mold); the material; the people responsible for operating the machine; and the environment.

MACHINE

Because the machine and mold can present problems independently and in concert they may pose the trickiest variable. Scoremaker's closed loop control compensates for such machine and mold variables as leaky valves, worn limit switches, faulty heater bands, cold or hot hydraulic fluid, uneven, worn or damaged molds. Whether new or old machine or mold, Scoremaker provides constant same-cycle automatic "fine tuning" of your machine.

MATERIAL

Material is probably the variable of greatest concern. Its characteristics may be vastly different even from one load of virgin material to another. Once regrind is introduced the characteristics may vary so much that it is unprofitable to use anything but a small percentage of regrind to virgin material at any one time.

Scoremaker equipped machines process all materials identically. Whether virgin, regrind, mixed, colored by powder or liquid, all materials can be shot uniformly to all sections of a tool. Automatic same-cycle "fine tuning" of the injection function assures that each cycle produces saleable quality parts.

PEOPLE

Whether the problem is doors left open too long, nozzles freezing off, cavities being blocked, parts hanging in the tool, unskilled molders or simple "knob twiddlers", the source is the same. People. Scoremaker compensates for the people variable by simply demonstrating that once set up for a job, a Scoremaker controlled machine constantly produces repeatable quality parts without any manual adjustment.

Scoremaker makes your employee's jobs simpler for them, and more profitable for you.

ENVIRONMENT

The environment changes from season to season, of course, but may even change from shift to shift. In certain cases, the environment can change drastically in terms of temperature or humidity. Mold set-up sheets made in winter and producing great parts may result in flash, or even tool damage, in summer. Material with certain characteristics during humid spring weather may behave with a radical difference during dry autumn months.

Scoremaker™ demands constant parts repeatability from your machines by automatically compensating for environmental changes. Even if those changes happen as rapidly as from one shift to another.

MACO IV®

MACO IV is a microprocessor based control system designed specifically for plastic injection molding and blow molding machine control. The system offers the advantage of a totally integrated package that includes sequence, timing, temperature, process control, and diagnostics all in the same basic control system. Use of a microprocessor as the nucleus of the system provides a means of achieving total machine control on an economical basis. The system includes an operator control panel with CRT (Cathode Ray Tube) for visual display of control parameters, a keyboard for data entry and recall, and a unique automatic setup data entry module.

Versatility is inherent to the system by nature of its design. Both hardware and software packages are available in modular form thus permitting tailoring of the system to meet specific requirements. In this manner, you need specify only those programs required to perform your specific machine functions.

One of the more salient features of MACO IV is the INSTA-SET™ automatic data entry module. This feature minimizes machine setup time of subsequent production runs by recording control setpoints on a magnetic card. The next time you want to set up the machine you simply insert the card into the reader/recorder and the setpoints are automatically entered into the system.

The CRT display and keyboard enable the operator to communicate with the control system. A five-inch CRT provides the operator with a visual display of control setpoints and actual measured variables, alarm status, relay ladder diagram program, and entry messages or instructions.

The keyboard is the vehicle by which the operator enters data into or recalls data from the system and is divided into two operational segments; a data entry section and a function select section. The function select section allows the operator to call up the various control display formats on the CRT. The data entry section is used by the operator to enter control parameter setpoints into the system.

Machine control, particularly injection molding, requires at a minimum; sequence control functions, timers to establish event durations, and temperature controls for control of melt temperature. All three of these basic control functions are built into the MACO IV system.

The sequence control program is contained in programmable read only memory (PROM) elements which can be programmed, erased and reprogrammed. Programming is performed via the control panel keyboard and CRT display.

Timing functions are built into the MACO IV system as part of the software program. The system provides a maximum of twenty timing functions each with a maximum range of 640 seconds. Timer assignments and settings are entered through the keyboard.

Temperature control functions are provided by a software program and temperature control module. The standard system software will accommodate a maximum of 20 inputs. Each temperature control module accepts inputs from four separate thermocouples. Control setpoints are entered through the operator panel keyboard and are displayed along with the actual measured temperature on the CRT display.

MACO V

MACO V is a microprocessor based programmable controller which monitors and controls critical extrusion process parameters on single or co-extrusion lines. It is a dedicated controller whose control functions are application oriented and designed specifically for total control of extrusion processes. MACO V is **not** just another general purpose programmable controller being applied to the plastics industry.

MACO V can be effectively applied to your sheet, film, profile, tubing, pipe, wire coating, fiber, or compounding lines and provide you the ultimate approach in centralized extruder line control. Through implementation of the latest in microprocessor control technology, MACO V consolidates all extruder control functions into one single centralized controller. Thus, MACO V replaces many discrete instruments from a number of different suppliers and you deal with a single reliable controls supplier who is dedicated to the plastics industry.

MACO V is inherently flexible to grow with your processing needs. Modular design allows control function expansion with minimal downtime. Modularity also offers economic benefits in that you specify only those control functions required by your process.

Man-to-machine interface is provided by the operator panel. The panel consists of the CRT, function and program keyboards, Insta-Set® read/record card reader, and the security keyswitch. Dedicated, color-coded pushbuttons allow instant display of the selected process variable plus operating setpoints. Alarm monitor and process monitor displays provide a visual readout of alarm status and process variable measurement on separate dedicated CRT displays.

Insta-Set® is a read/record system which provides storage of all setpoints and tuning constants on magnetic cards. Thus, once proper extruder operating values have been achieved, they can be recorded and used for startup the next time the product is run. For extrusion line startup, the system has the capability of accepting multiple cards. Startup times and entry errors are greatly minimized.

Extruder controllers belong at the extruder where operators have access to all necessary control adjustments and measured variable display. MACO V is designed for the plant environment and operator accessibility. For operator convenience, the operator panel may be remotely located away from the MACO V and power panel enclosures.

Executive control programs are contained on pre-programmed EPROMS (ultraviolet light erasable programmable read only memory) totally eliminating the need for computer or microprocessor programming knowledge. Programs are functionally blocked to facilitate controller expansion; often times requiring the addition of a single PROM and the appropriate hardware module. Field programming capabilities include sequence or logic programming plus control loop configuring and tuning. Field programming does not require any special technical skills and is performed via the operator panel. The field programming routines are designed to be performed by your process engineers to meet the needs of your process. Program menus and displays guide the programmer through the routines.

Barber-Colman supplies complete instruction manuals with each controller and a staff of application engineers is available for assistance. We also offer regularly scheduled training schools on all our products.

For your extrusion needs, MACO V can provide the following control functions:

(Note: Some of the Controls and Features are Optional)

1. **Heat-Cool Control of 52 Temperature Zones**
2. **Process and Deviation High and Low Alarms for each Temperature Zone**
3. **Heater Burnout Detection**
4. **Thermocouple Break Detection and Upscale Deflection for each Temperature Zone**
5. **Melt Temperature Control**
6. **Four Drive Control Functions plus a Ratio Output Function with Four Separate Adjustable Outputs**
7. **Melt Pressure Control**
8. **Pressure Monitoring and Alarming of Six Control Points**
9. **Seven Day Clock**
10. **Logic/Sequence Control**
11. **Counters and Timers**
12. **Alarm Monitor Display**
13. **User Programmable Process Monitor Display with up to Seven Process Variables**
14. **Logic Control Diagnostics**
15. **Field Programmable**
16. **Thickness Gauging**
17. **Computer Interface**

The MACO VI Parison Programmer/Controller is a microprocessor based system designed for complete control of parison forming machines. The controller integrates all machine functions such as sequence, timing, temperature, parison profiling, and counting into a single controller. Exclusive Insta-Set® minimizes machine startup by entering all control setpoints in a matter of seconds.

The operator panel CRT display and keyboard provide the operator with a readily available digital readout of key operating variables. Tuning parameters and control setpoints are entered through the keyboard thus eliminating mechanical adjustments.

All executive control programs are contained on preprogrammed PROMs totally eliminating the need for computer or microprocessor programming skills or languages.

Field programming capabilities include sequence and alarm programming plus control loop tuning and is performed through the operator panel. Program menus and CRT displays guide the programmer through the routines.

The MACO VI Blow Molding Controller can provide parison programming outputs for two die heads having the same profile. As an option, the controller can be easily expanded to control four die heads using two profile signals. Separate weight and die gap signal outputs are provided for each die head. Profiles may be either position based (accumulator machines) or time based (continuous extrusion machines).

Temperature control consists of up to 16 heat/cool zones plus four manual (open-loop) zones. All 16 heat/cool zones are field programmable for: 1) single or dual outputs, 2) time or current proportioning on heating outputs and on-off and time or current proportioning on cooling outputs, and 3) full three-mode control.

Every MACO VI controller includes 27 digital timers each with a time range of 0 to 640 seconds and with a settability of .02 seconds. In addition, the controller can be specified to include 14 digital counters each with a range of 0 to 9999 counts.

To replace machine limit switches, the controller may also include linear positioning functions for control of movable machine elements. Up to four separate linear positioning functions can be specified. Each function has seven control setpoints. For those applications requiring more than seven controlled setpoints, functions can be combined to provide up to 14 controlled positions.

For control of electrohydraulic pressure or flow control valves, MACO VI can contain up to four separate control functions. Each function provides a maximum of seven controlled pressure or flow setpoints. Since electrohydraulic valves require a current input signal, the output of the pressure or flow card is applied to a Model 907 power supply which in turn provides the drive to the valve.

Setpoint memory retention is provided by a gelled electrolyte battery. The battery charger assembly insures that the battery is maintained in a fully charged state. The combination of battery backup and Insta-Set® provides benefits not available in most programmable controllers.

Machine Commander

The MACO VI Controller can be specified as part of a Machine Commander control system. Here Barber-Colman will design (to your specifications) and provide the machine control panel. Included in the panel will be the MACO VI controller, solid state contactors, electrohydraulic valve power supplies, etc. As part of the overall control package, Barber-Colman can also supply pressure transducers, linear potentiometers, and thermocouples. Thus, Barber-Colman can provide single-source responsibility for your complete machine control system.

REDUCING I.M.M. POWER CONSUMPTION THROUGH CONTROLS

Neil Atkins/James Bohenko
Farrel Machinery Group
Emhart Corp.

INTRODUCTION

In the past decade, we have seen the "state of the art" in I.M.M. controls advance at an unprecedented rate. Relay controls have been replaced with solid state. Shortly thereafter, microprocessor controls were being applied.

No longer does one have to be a computer expert to take advantage of the capabilities of microprocessors. With the high level languages now available, the process engineer-who is the best person for the job-can now program the machine to meet the exacting requirements of a particular job.

Clearly, the progress of I.M.M. control designs has had a positive impact on productivity, part quality and machine efficiency. From a controls standpoint, productivity and part quality have naturally been the primary criteria in determining control strategy. However, as the cost of energy continues to rise, enhanced machine efficiency through improved controls, control stragegy and other means will have to be considered.

OBJECTIVES

The objectives of this study were to identify machine and processing inefficiencies and to develop control strategies to reduce or eliminate these inefficiencies where practical.

TEST EQUIPMENT

We conducted our study in the field in order to evaluate a varied number of machines and processes in a production environment. Therefore, the test equipment had to meet the following requirements. It had to be portable and still provide the data required and, it had to be installed without interrupting production.

Before conducting our study the equipment was tested in our lab for accuracy and found to be within the manufacturer's specifications.

The following equipment was used in our study:

1. Hioki Model 3134 clamp on power tester.
2. Hioki Model 3141 power integrator.
3. Gould high speed two channel chart recorder.

DISCUSSION

Controls for injection molding offer considerable potential to improve machine and processing efficiency. They do not however, automatically improve efficiency. Close evaluation of the machine and of the process must be made in order to implement the most effective control strategy for the application.

We evaluated a total of fourteen machines ranging from 450 to 2500 tons.

Our first task, was to determine actual power consumption for each discrete part of the process. This was accomplished by using a power analyzer, a power integrator and a two channel strip chart recorder. The power analyzer digitally displays instantaneous power draw (KW) up to 999 KW. Simultaneously, we recorded I.M.M. KW demand on the strip chart recorder. The power integrator was used to sum the total power used over a given period of time (1 min. to 99 hrs). This was very useful in comparing various control strategies and their effectiveness over a period of time.

For each test, all other relevant machine parameters were recorded, see Figure 1 and 2.

From a controls standpoint, we found direct and indirect areas for potential energy savings, see Figure 3.

Generally, machine control based on events (control elements), rather than trial and error timer settings improved process efficiency and reproducibility. Figure 4 shows a list of standard control elements. Of these control elements, the mold cavity transducer has been accepted as an important standard for I.M.M. process control. One drawback is that they require the mold to be modified for the transducer to be inserted.

An additional control element is the (patented) Farrel V.R.M. Velocity Range Monitor.

The Farrel V.R.M. is a microprocessor based system that utilizes the information derived from the injection ram kinetics to accurately deduce when mold packing, and hence, optimum pressure switchover should occur.

When material is packed into the mold, the injection velocity drops from its set value toward a much lower value. The packing detector automatically senses the value of injection velocity, below the normal value, where switchover from high to holding pressure will occur. Depending upon how close it is practical to set this threshhold velocity to the actual velocity, the high injection pressure can be correspondingly limited and the possibility of flashing reduced.

After hold pressure is established, the system looks for zero injection velocity. This zero velocity signal cuts off hold pressure and initiates plastication for the next shot. A hold timer can be set to cause a preset time to elapse between the time zero velocity occurs and hold pressure is dropped. Logic is incorporated in the control to actuate an alarm if the injection cycle is prematurely aborted due to nozzle freeze-off or barrel restriction, etc.

The following description of operation illustrates, in a sequential fashion, the manner in which the V.R.M. operates.

During the injection portion of the molding cycle (see Fig.5):

1. Injection takes place under a high pressure setting. The actual injection pressure (depending on rheological behavior of the material) is that required to produce desired ram velocity. The average velocity is computed continuously by the controller.

2. When packing of material into the mold begins, the injection ram velocity will drop off. The detected drop off in velocity signals the switchover from high volume to a holding pressure level.

3. In the general case, the ram will continue to "creep" toward the mold at a rate determined by the degree of material shrinkage during cure. The ram will stop creeping forward when the flow path into the mold has been sealed. This second drop off in velocity signals the system that pressure can be relieved, the nozzle shut off valve closed, and plastication initiated. The primary advantage of this feature is that the transfers of injection pressure from high volume to holding to pressure removal take place specifically when they should occur, i.e., based upon events rather than trial and error time settings.

We tested the V.R.M. from an efficiency standpoint with the following results (a chart recording of KW demand for injection is shown in Figure 6):

During injection, 110KW was being drawn. The duration of injection was about 3 seconds. The fill portion of injection took place in approximately 1.5 seconds (see Fig. 7). Beyond this point, high volume is no longer required, although the mold has been filled, high pressure must be maintained to pack the part. By using process control to monitor the velocity decay on the injection ram - a point after which the high volume is no longer required - can be seen. The dark area under the curve in Figure 7 represents energy saved without compromising part quality.

Integrating the total power required over a period of time without process control, we found that the power being consumed was 47.0 KWH. Integrating the total power required over the same period with process control, we found our power consumption dropped to 39.5 KWH. The power demand was reduced by 7.5 KWH. This represents a savings of 15%.

The customer's plant is located in New York City. Their power costs are high, about \$.10/KWH. They run 24 hours a day, 6 days a week, 7,488 hrs per year.

(7,488 hr/yr) (7.5KW/Hr) = 56,160 KWH/Yr SAVED/MACHINE

(@ \$.10/KWH) (56,160 KWH/Yr) = \$5,616/Yr SAVED/MACHINE

The \$5,616 represents money that can be saved by implementing the process control previously described. Similar savings could possibly be realized on their other machines, based on our findings.

FIGURE 1

TYPICAL DATA

IMM Cycle	STROKE (Inches)	Time (Sec.)	Hydraulic Pressure	KW
Clamp Close		1.0	200 psi	54
Clamp Lock-up		5.0	1100 psi	
Injection	2.25	2.2	1900 psi	100
Holding		0.5	1600 psi	25
Screw Recovery		2.4	600 psi	37
Decompression	0.5	-	-	-
Clamp Opening		0.7	150 psi	12
Eject		0.75	500 psi	50
Clamp Open		0.4	-	

TEMPERATURE CONTROL	DEG. °F	KW Peak	KWH
Zone 1	481	4.27	.25
Zone 2	481	4.57	1.99
Zone 3	481	4.70	1.68
Stock Temperature			
TOTAL			

FIGURE 2

TYPICAL DATA

MATERIAL

Material Mfg N/A

Grade General Purpose

Type Styrene

MOLD

Projected Area 150 in^2

Runner Diameter .25 in.

Type Gate Sub-Gate

Part Wt. 4.164 gm

Sprue & Runner Weight 42 gm

Type Sprue & Runner Hot Sprue Bushing

#Cavities 48

OIL TEMPERATURE 110°F

IMM MODEL 450M52

TIMER SETTINGS

T_1 2.1

T_2 0.2

T_3 3.0

T_4 1.2

FIGURE 3

AREAS TO REDUCE POWER CONSUMPTION

1. Direct reduction of machine energy requirements/cycle.

    A) Reduction of overall cycle time (using an event rather than trial and error timer settings).

    B) Reduce duration of high energy demand (shut off high volume pumps when they are not required).

2. Indirect reduction of energy requirements.

    A) Reduce material consumption (prevent part overpacking).

    B) Hold accurate part dimensions (minimize rejects).

FIGURE 4

STANDARD IMM ELEMENTS OF CONTROL

EVENT	ELEMENT OF CONTROL
Injection Boost to Hold Pressure:	1) Ram position-Analog or Digital 2) Cavity pressure mold-Analog 3) Ram hydraulic pressure-Analog 4) Timed-Digital
Injection Hold:	Timed-Digital

Additional Elements of Control

Injection Boost to Hold Pressure:	Ram velocity decay - Digital or Analog
Injection Hold:	Zero velocity - Digital or Analog

GENERAL I.M.M. ELEMENTS OF CONTROL

	Analog Data		Digital Data	
	Number	Type	Number	Type
INPUTS	36 approx.	Temp. Pressures Speeds Distance	85 approx.	Limit Switches Command " Pushbuttons
OUTPUTS	36 approx.	Temp. Pressures Speeds Distance	85 approx.	Control Signals Solenoids Indicating lights Alarms

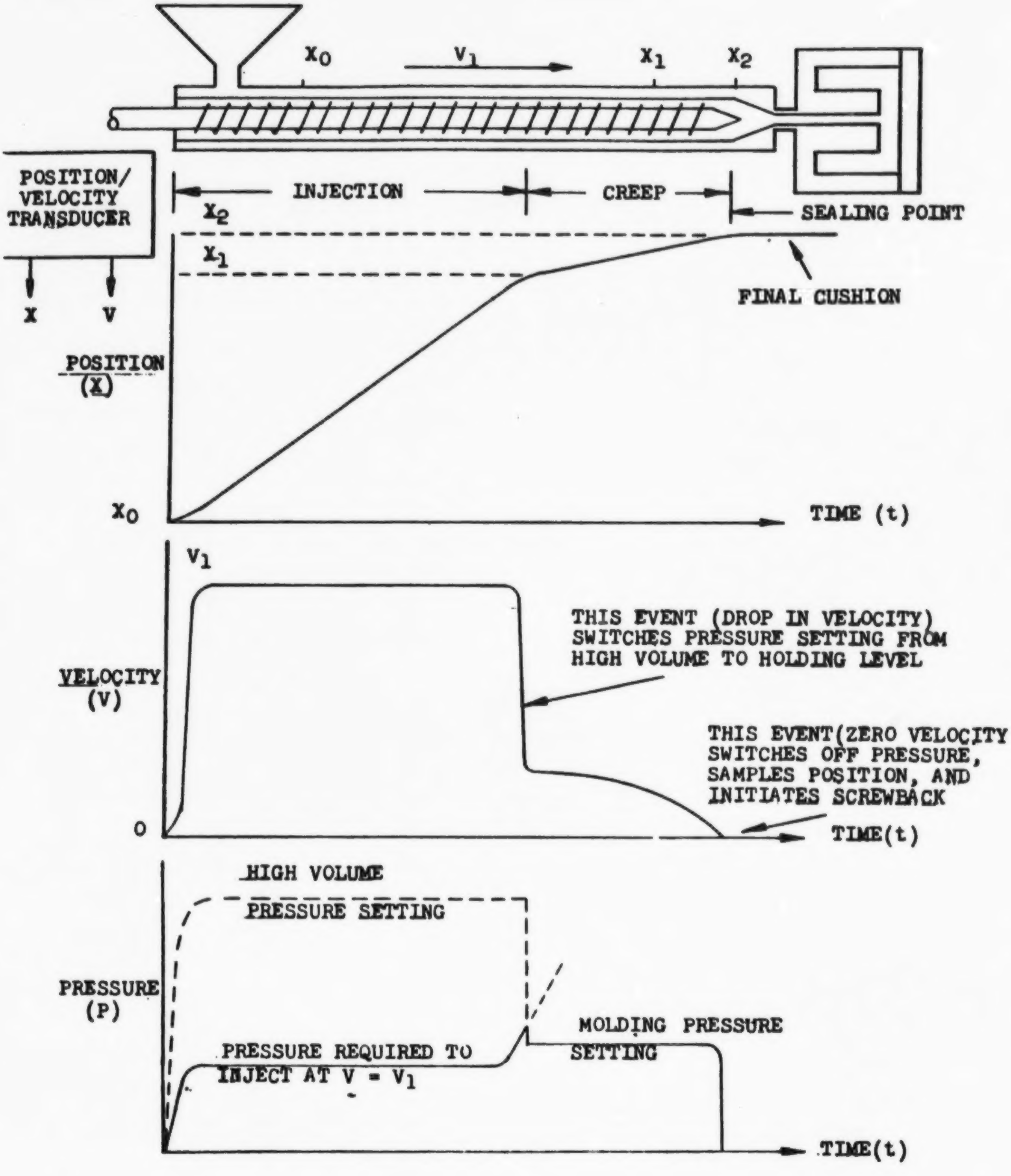

X0
V1
X1
X2
POSITION/
VELOCITY
TRANSDUCER
X
V
INJECTION
CREEP
SEALING POINT
X2
X1
FINAL CUSHION
POSITION
(X)
X0
TIME (t)
V1
THIS EVENT (DROP IN VELOCITY)
SWITCHES PRESSURE SETTING FROM
HIGH VOLUME TO HOLDING LEVEL
VELOCITY
(V)
THIS EVENT(ZERO VELOCITY
SWITCHES OFF PRESSURE,
SAMPLES POSITION, AND
INITIATES SCREWBACK
0
TIME(t)
HIGH VOLUME
PRESSURE SETTING
PRESSURE
(P)
MOLDING PRESSURE
SETTING
PRESSURE REQUIRED TO
INJECT AT V = V1
TIME(t)

FIGURE 5 - RAM POSITION AND VELOCITY AND INJECTION PRESSURE VERSUS TIME WHILE MOLD IS BEING FILLED

FIGURE 6

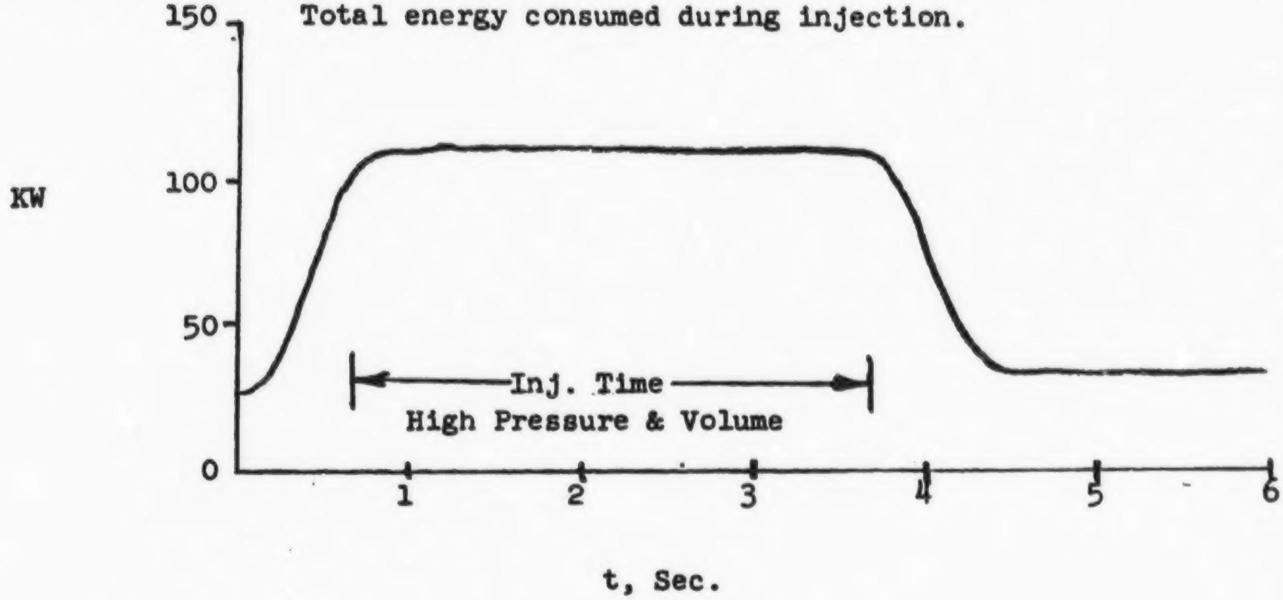
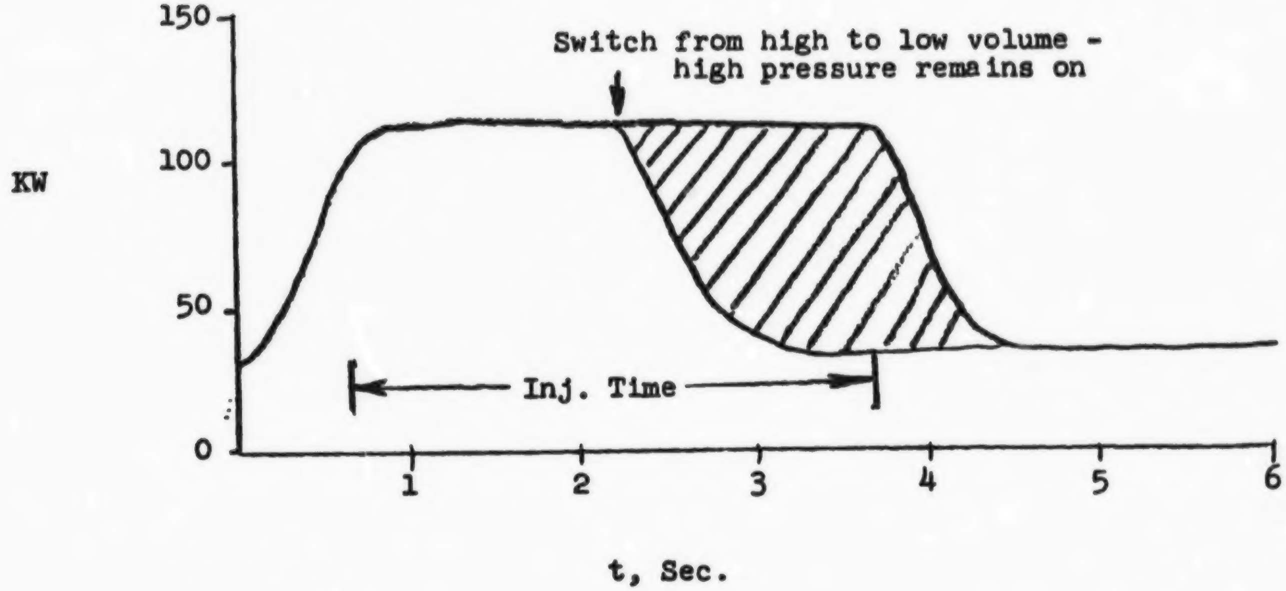


FIGURE 7



APPENDIX J.1.

AUXILIARY EQUIPMENT

Note- The following literature is provided to assist the processors but its inclusion here does not constitute any endorsement.

1. Energy Efficient Dryer
   Connair Canada Ltd.,
   Mississauga, Ontario

2. New Drying Technology
   Dehydron - Plastics Machinery Inc.,
   Markham, Ontario

3. Energy Saving Dryer
   Whitlock - Enplas Inc.,
   Scarborough, Ontario

Power Miser 1 and Power Miser 2 are two new, energy-saving design options available on Conair's Somos Dryers. For processors who must predry hygroscopic materials,they can save thousands of dollars in energy costs annually.

One, or both, of the Power Miser options may be factory-installed on ConairDryers or installed later, in the field, as retrofit components.

Power Miser 1 monitors the dryer's process air dewpoint and keeps dryer desiccant cartridges from indexing into regeneration until they are near saturation. Normally, regeneration is done on a timed basis. Power Miser 1 allows running low-moisture-content materials with a minimum of energy-intensive, high-heat regeneration cycles. A panel light signals when Power Miser 1 is operating and an additional light warns in the event of an unsatisfactory dewpoint.

Power Miser 2 is a microprocessor-based monitoring system which automatically adjusts process air cfm to the amount of material actually being processed. In many drying applications, actual throughput is far less than capacity of the dryer and energy is wasted heating unneeded air. This oversizing of equipment can cause excessive return air temperatures and require an aftercooler to remove excess heat prior to dehumidification.

By matching cfm to throughput, only the air actually needed for drying the material is delivered to the drying hopper and no heat build-up can occur. Air heaters cycle less often because of the reduced air flow, eliminating unnecessary power use.

An additional option now offered by Conair on all Somos-type dryers is a Process Protection controller which senses excessive temperatures in the drying hopper and shuts down the dryer automatically. The temperature limit is adjustable to meet varying process requirements.

Circle 709 on Reader Service Card

New system shortens drying time, saves energy

JRF Systems of Mississauga, Ont has developed a highly efficient method for the extraction of moisture from hygroscopic thermoplastic materials. The method differs from conventional pre-drying systems by making use of the energy from molding machinery which would normally be lost. The new unit facilitates almost immediate start of production with undried materials regardless of atmospheric conditions.

The unit, called the *Dehydron*, stands 28 inches high, and is designed to fit between the hopper and inlet of a molding machine. It will process up to 120 lbs of plastic an hour using only 350 to 400 watts of electricity, and has been tested successfully on nylon, polycarbonate, thermoplastic polyester and ABS.

The *Dehydron* functions in the following manner. Wet material is loaded in the hopper above the unit. Prior to and during processing the material is pre-warmed in a central core which is heated by use of heater bands totalling approximately 300 watts. These heater bands are controlled by the *Dehydron's* own power control unit.

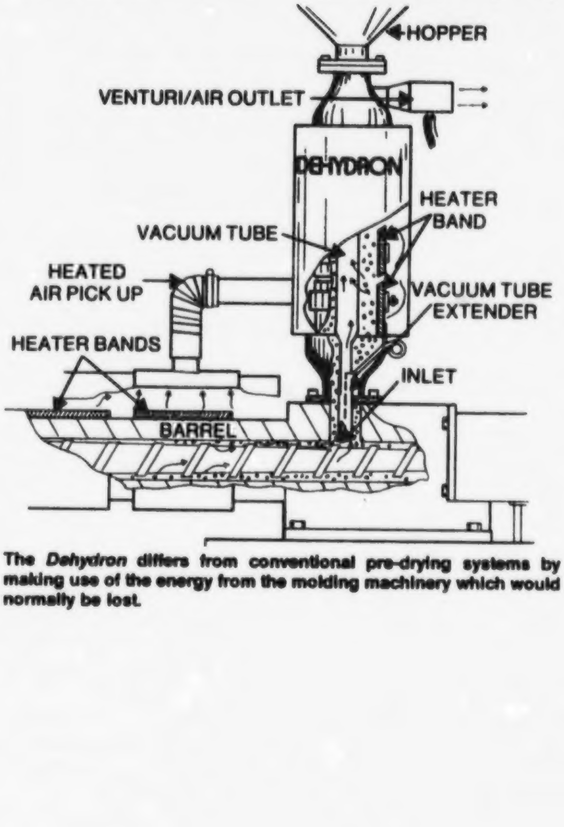
A venturi at the top of the unit extracts much of the moisture from the surface of the resin. This pre-warming is assisted by the circulation of hot, dry air extracted from around the injection barrel.

As the resin reaches the feed throat on which the unit is mounted, the next phase takes place. The same venturi removes internal moisture from the resin, using vacuum suction, as it is being plasticized within the barrel.

The *Dehydron* uses less than 5% of the energy used by conventional drying systems, and has been approved by government as an energy saving device. Purchasers are entitled to an energy savings refund in Canada and a federal energy tax credit in the U.S.

JRF, under the direction of Jarro Kopernicky and Frank Kis, are presently developing units which are expected to have more capacity, as well as an automatic materials loader to be used in conjunction with the *Dehydron*. A new company, Dehydron Sales in Markham, Ont, has been formed to market the *Dehydron* drying system.

Plastics Machinery of Markham has been appointed by Dehydron Sales as its Canadian agent. A U.S. dealership network is currently being set up.



The *Dehydron* differs from conventional pre-drying systems by making use of the energy from the molding machinery which would normally be lost.

Energy Saving Heated Plenum with Built in Heater

Whitlock has re-invented the drying hopper and made dehumidifying more energy efficient for hygroscopic materials. Our kilowatt conscious plenum design with patented built-in heaters solve the problem of heat loss through hoses which connect the drying system.

In conventional dryers, air is dehumidified and heated in the drying unit. This hot, dry air must travel through several feet of hose to reach the plenum where drying takes place. The resultant heat loss is enormous and becomes more costly as hose diameter and length increases.

Whitlock's new drying method solves the problem of heat loss by locating drying heaters in the plenum hopper instead of the drying unit. This unique design is made possible by an innovative system of baffles which shield plastics from excessive exposure to heaters which are located in the plenum base.

Energy savings are twofold. First, there's no heat loss in transport, and air does not have to be overheated to compensate for heat loss. Electrical savings amount to $450 or more per year for an average size plenum. Savings for large plenums and central systems are even greater.

Wide Range of Sizes

Drying hoppers with internal heaters are available for 50 lb. to 6000 lb. plenums and have from three (3) to sixteen (16) electric heating elements which are capable of providing temperatures up to 400° F.

How They Work

In the accompanying schematic, dry air from the desiccant unit enters tangentially at the bottom of the plenum hopper and rises past the heaters, which are shielded by cylindrical metal baffles to direct the air flow. Air is baffled downward and out through a tangential opening to a second baffle with a downward air flow pattern. Air then flows upward through an air-diffuser cone, which has openings large enough for hot air to diffuse into the plenum chamber but too small to permit plastic pellets to fall through them. Air exits from the plenum chamber and returns to the desiccant dryer through a hose—as in a standard system—but for drying only, not for heating. Cooler air hoses add an additional safety feature to the new systems.

APPENDIX K.1.

ENERGY MONITORING EQUIPMENT

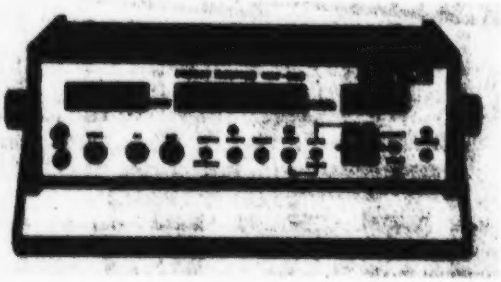
Note- The following literature is provided to assist the processors but its inclusion here does not constitute any endorsement.

1. Energy Monitor
   Soar Co., Ltd.,   Enplas Inc.,
   Scarborough, Ontario

2. Energy Monitoring Equipment
   Hioki E.E. Corporation
   Douglaston, N.Y.

5. Power Consumption in Actual Molding Operations

Photo 2. Energy Monitor



In general, a molding machine is compared with its counterpart machines by the percentage of power saving achieved, or by the expression 'power-saving of so many percent.' However, what is actually necessary is not a relative comparison but rather a performance warranty in absolute values, or specifically the actual quantity of electric power consumed per cycle of machine operation. This will truly be an economic comparison, on the basis of which some proper energy-saving measure may be adopted.

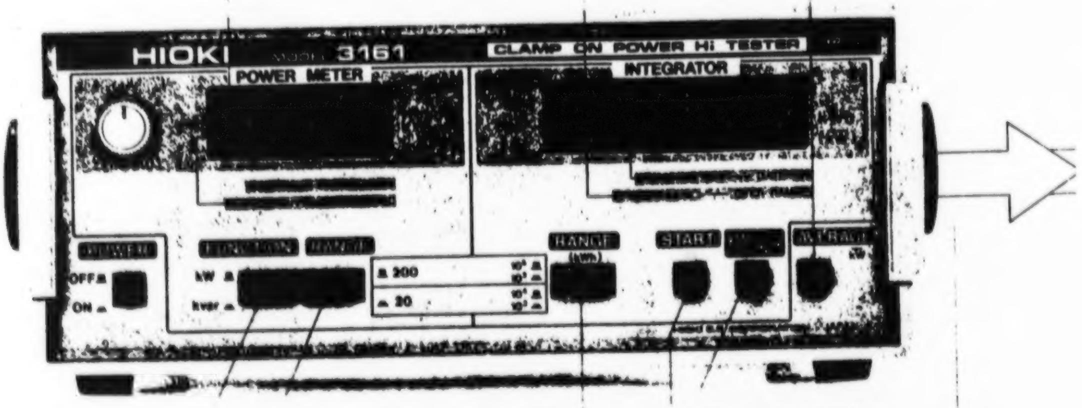
The adoption of this method of performance evaluation will naturally require measurement of all the power consumption rates of existing machines, for which much time will be rerequired by conventional types of instruments, in addition to the measurement of details being quite difficult.

In connection with such studies of energy saving, Soar Co.,Ltd. has developed an Energy Monitor* (Photo 2) which is very convenient for measuring the power requirements of injection molding machines, and which we recommend for use in measurements associated with energy saving.

Power Meter Display
The 3½-digit LCD reads to 1999. Overrange is indicated by all digits going blank except the MSD "1" and decimal point.

Integrator display
The integrator display features a 6-digit LCD with a maximum reading of 999999. Counter overflow causes the MSD decimal to blink, and the count immediately starts over from 0. The colon [:] blinks when the counter is in the run status; and is extinguished on hold.

Mean power measurement
Normally difficult-to-read displays of power measurement in severely fluctuating lines are solved by the built-in averaging circuit.
Mean power value is output to a static display at 36 second intervals. A new display showing the mean power measurement will be produced every 36 seconds after this mode is set.



Function switch
Selects the effective or reactive power measurement mode.

20/200kW (kvar) range selector
Measurement range may be selected according to circuit loading.

Convenient carrying case
The instrument, clamp-on sensors, and test leads fit neatly into the carrying case.

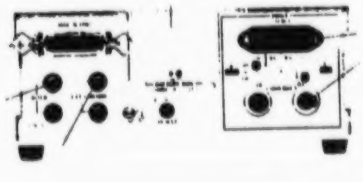
Records of power consumption
A printer may be connected to data output to obtain hard-copy results of integration data or mean power measurements.

Output terminal
A 2V DC output for full scale value (2000 count) in each power meter range is transmitted through the output terminal, and may be used to drive a recorder for obtaining hard-copy results of power line fluctuations.

Integration measurements to 100,000kWh
Range switch selection on the power, meter and integrator are used in combination to provide a minimum resolution of 0.0001kWh, and range to a maximum reading of 100,000kWh.

Integration start button
This button starts integrator operation; clearing counter run, hold, or mean power measurement status first. (Power readings preceded by a minus sign will not be integrated.)

Battery powered for portability
The instrument can be used on four "C" cell batteries for 48 hours – meaning that measurements may be made where an AC outlet is not available.



Externally controllable integration time

12-position handle
The large bucket-bail type handle can be locked in any of 12 positions within a 360° arc.

Integrator display HOLD-RUN
Depressing this button stops the display for a reading of total power integration since integration start. The counter however, continues to increment, so when the button is released the display will once again show present counter contents.

Two-wattmeter method for measurement fidelity
Effective power measurements are accurate even in unbalanced circuits, and measurement fidelity is maintained even in lines containing higher harmonics, HIOKI's unique clamp-on sensor assures unparalleled accuracy in power measurement.